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# REPORT OF PROGRESS IN WARM-AIR FURNACE RESEARCH

BY

A. C. WILLARD

[THIS BULLETIN IS THE FIRST OF A SERIES ON WARM-AIR FURNACE RESEARCH]

BULLETIN No. 112

ENGINEERING EXPERIMENT STATION

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The control of the Engineering Experiment Station is vested in the heads of the several departments of the College of Engineering. These constitute the Station Staff and, with the Director, determine the character of the investigations to be undertaken. The work is carried on under the supervision of the staff, sometimes by research fellows as graduate work, sometimes by members of the instructional staff of the College of Engineering, but more frequently by investigators belonging to the Station corps.

The results of these investigations are published in the form of bulletins, which record mostly the experiments of the Station's own staff of investigators. There will also be issued from time to time, in the form of circulars, compilations giving the results of the experiments of engineers, industrial works, technical institutions, and governmental testing departments.

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

BULLETIN No. 112 MAY, 1919

# REPORT OF PROGRESS
IN
# WARM-AIR FURNACE RESEARCH

CONDUCTED BY
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

THE
NATIONAL WARM-AIR HEATING AND VENTILATING ASSOCIATION

BY

A. C. WILLARD
PROFESSOR OF HEATING AND VENTILATION

## ERRATA

ge 33, line eight: *for* "one" *read* "two".
ge 42, Table 5, fifth column, third line from top: *for* "Q-4" *read* "A-4".
ge 43, line two of text: *for* "2.56" *read* "4.3".
ge 43, line three of text: *for* "65.38" *read* "67.32" and *for* "34" *read* "32".
ge 57, line seventeen: *for* "1919" *read* "1918" and *for* "January 16, 1918" *read* "January 16, 1919".

ENGINEERING EXPERIMENT STATION
PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

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*See also paper by W. E. Pratt of the Furnace Research Staff, "Comparison of Warm-Air Furnace and Hot-Water Heating Plants."

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# REPORT OF PROGRESS IN WARM-AIR FURNACE RESEARCH

## I. Preliminary Statement

This Bulletin is a preliminary report of progress under the present coöperative agreement between the National Warm-Air Heating and Ventilating Association and the University of Illinois for an investigation of warm-air furnaces and furnace heating systems. The agreement was formally approved in August and became operative on October 1, 1918. Such work as is here reported was done between October, 1918, and May, 1919, and the results are set forth in a more or less summarized form giving such information and typical test data as will prove of most interest to the Association for consideration at its meeting in Columbus, Ohio, on June 11, 1919.

Under the terms of this present agreement, the Association is to provide funds in an amount not to exceed $8,000 for a period of one year to defray part of the expense of this research work. The University through its Engineering Experiment Station is to assume the responsibility of maintaining the necessary staff and conducting the investigation and, of course, it is further responsible for the reliability and unbiased character of all results obtained. To this latter end, the Engineering Experiment Station reserves the exclusive right to publish any and all test data and results. Such publication will be made from time to time in official bulletins of the Station for the purpose of furnishing whatever scientific and technical data are developed in this work for the benefit of the engineering profession and the warm-air furnace industry.

It should be noted at the outset of this discussion that the fundamental ideas involved in the methods used in this investigation, as well as the furnace plant itself and its essential features, were developed and put into operation by the Department of Mechanical Engineering of the University of Illinois in the spring of 1918. Realizing the great possibilities in extending the scope and value of the investigation by enlisting the active support and interest of the Manufacturers' Association, a formal proposal for a coöperative investigation, presented in Appendix II, was made to the Association in June, 1918, at its annual meeting in Milwaukee, Wisconsin. This proposal received the unqualified approval of the Association.

### Objects of the Investigation

The principal objects of the investigation are briefly stated as follows:

(1) To determine the efficiency and capacity of commercial warm-air furnaces under conditions similar to those existing in actual installations with leaders, stacks and registers to form a complete system.

(2) To determine satisfactory and simple methods for rating furnaces so that the proper size and type of furnace can be definitely selected for the service required.

(3) To determine methods of increasing the efficiency and capacity of furnace heating equipment and the advantages or desirability of certain types of design.

(4) To determine the heat losses in furnace heating systems and the value of insulating materials as affecting the economy of the furnace or the leaders and stacks, and finally of the system as a whole.

(5) To determine the proper sizes and proportions of leaders, stacks, and registers supplying air to first, second and third floors.

(6) To determine the friction losses in the cold air or recirculating ducts and registers and their proper size, proportions and arrangement or location.

(7) Eventually, to make a study and comparison of outside and inside air circulation as affecting the economy and operation of furnace systems.

FIG. 1. THE MAIN PLANT, SHOWING PRESENT ARRANGEMENT. NOTE INLET CALIBRATION PLANT AT THE LEFT

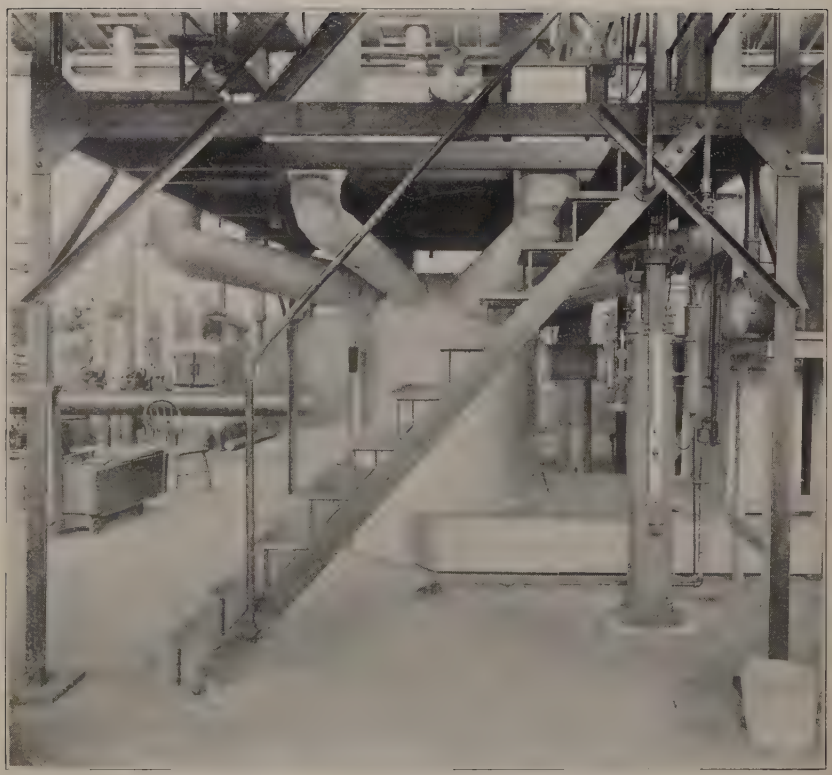


FIG. 2. SIDE VIEW OF MAIN PLANT, SHOWING UEHLING $CO_2$ APPARATUS AT RIGHT, WITH AIR INLET CONNECTIONS BEHIND UEHLING APPARATUS

## II. Special Problems Involved in the Measurement of Temperatures

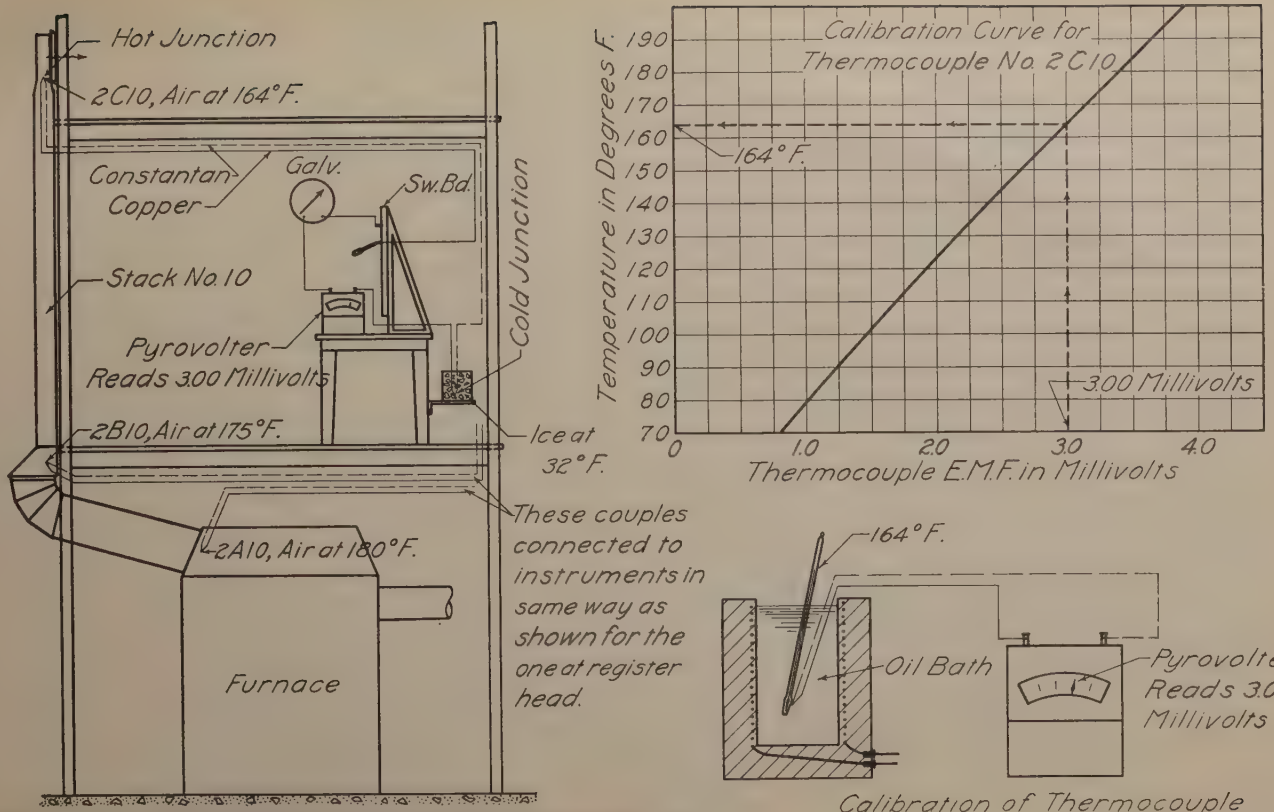
This investigation involves two special problems the correct solution of which is absolutely vital to its success. Their existence was recognized from the outset, and the difficulties involved in their solution account for the fact that practically no testing work using a complete plant has ever been done in the field of gravity furnace heating.

### Measurement of Temperatures

The first problem involves the accurate measurement of air temperatures at a great many points ranging from the air inlet, through the furnace casing to the bonnet, and then through leaders, boots and stacks to the register outlets on the various floors. From a consideration of the fact that a ten-leader plant (Figs. 1 and 2) is in operation in these tests it will be apparent that from forty to fifty or more temperatures must be measured, checked and recorded every time a set of readings is taken during a test. As from five to six sets of readings are necessary on each test it is evident that a very elaborate and an accurate system (Fig. 3) of temperature measurement is required.

By the use of thermocouples which are connected to a very sensitive milli-voltmeter and galvanometer located at a central switchboard (Fig. 4) these various temperatures are quickly and accurately indicated in terms of electrical units which are later converted into degrees Fahrenheit for use in making computations. This important and unusual feature of the testing plant has been developed by Professor A. P. Kratz who has also devised a very convenient portable equipment in the shape of an electrically heated calibrating apparatus for checking the accuracy of any thermocouple at any time without removing it from the plant.

*Discussion of the Temperature Measurement System Now in Use.* — Since the temperatures to be measured in this investigation are in most cases comparatively low, and hence the electromotive force in the circuit small, the use of the deflection method was considered inadvisable because the readings in this case are not independent of the resistance in the circuit and are liable to errors due to change in this resistance. The Pyrovolter was found to be sufficiently accurate for the purpose




Calibration of Thermocouple

IG. 4. THERMOCOUPLE SWITCHBOARD SHOWING PYROVOLTER, COLD JUNCTION BOX, AND WIRING CONNECTIONS

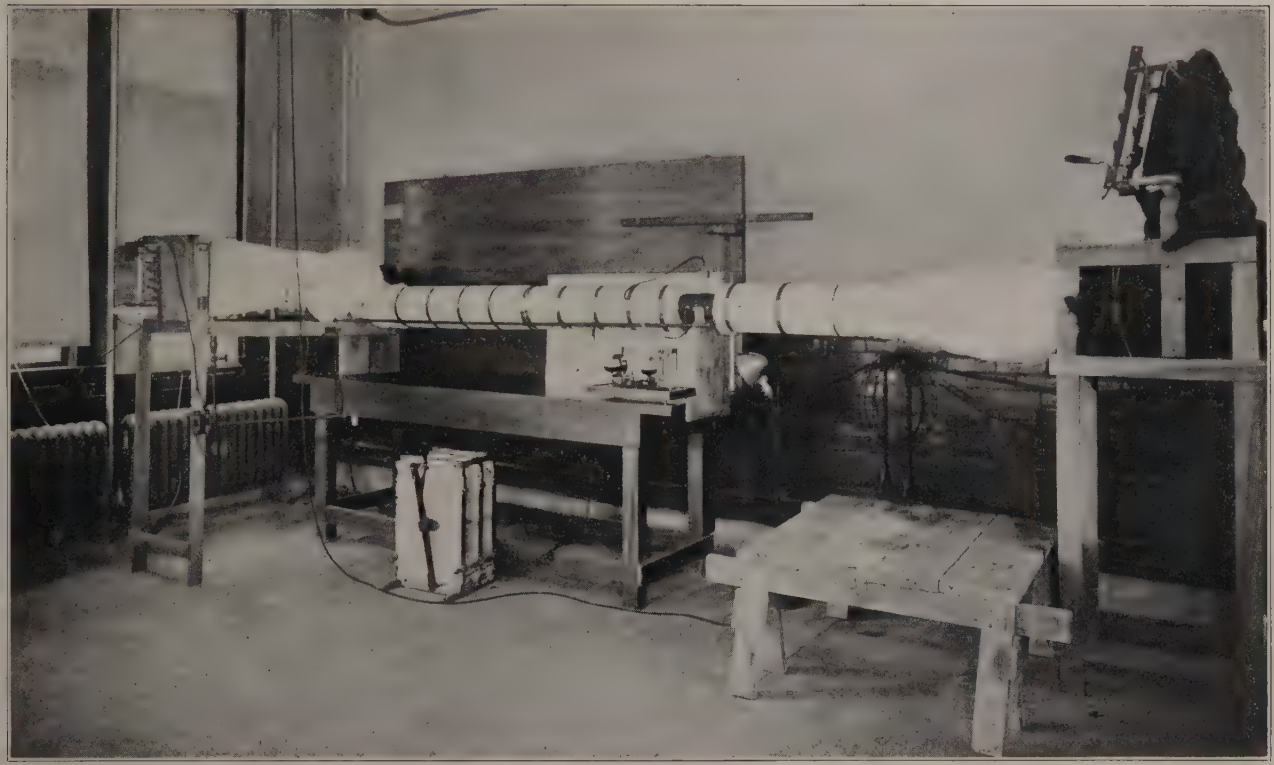


FIG. 5.—ANEMOMETER CALIBRATING PLANT FOR OBTAINING CORRECT OUTFLOW AT REGISTER FACES

in view, and since the principle involved embodies the measurement of the electromotive force with zero current in the circuit, the same as with the potentiometer, thus making the readings independent of the external resistance, it was adopted. In using this instrument, the electromotive force of the couple is balanced against the fall of potential across a fixed resistance, and the current which produced this fall is immediately read on a galvanometer placed in the circuit in which the fixed resistance is located. The galvanometer is calibrated to read fall of potential instead of current, thus giving the electromotive force of the couple directly. The permanency of calibration is, therefore, a function of the permanency of the magnet in the galvanometer, while the precision of reading is a function of the accuracy with which the initial balance was attained. The accuracy of the initial balance was greatly increased in the present case by the addition of a sensitive auxiliary galvanometer placed in the thermocouple circuit.

Two factors influenced the choice of metals from which the couples were made. The first of these, i. e., the homogeneity of the metal, affects the permanency of calibration. Non-homogeneous metals are liable to change after a period of service, producing a more or less permanent change in reading, and are also liable to the production of parasitic currents causing temporary inconsistencies in readings. The second of these factors, i. e., the magnitude of the induced electromotive force per degree difference in temperature between the hot and cold junction, affects the precision of reading. The metals chosen as having the most fortunate combination of the two characteristics mentioned were copper and a copper-nickel alloy known under the trade name of constantan. This combination gives a precision of about 42 deg. F. per millivolt. The pyrovolter in use was especially constructed to give a direct reading of 0.01 millivolt. Accordingly, the precision attainable is 0.42 deg. F. It has been found possible to repeat readings to within 0.01 millivolt, or 0.42 deg. F., with the present arrangement when the hot junction was placed in a constant temperature bath at 68 deg. F. This was done with a series of six readings covering a period of one-half hour. It has also been found that calibrations can be repeated to within less than two degrees, with couples subjected to the present service. A recalibration of similar couples after several months continuous service in a boiler flue at about 600 deg. F. also proved that the reading had not changed more than about two degrees. It is, therefore, considered that the readings of the couples are reliable, and are accurate within one or two degrees.

The junctions of the couples were all formed by fusing the two wires together in an air-gas flame. It was found possible to form a strong joint in this manner. Some question was raised concerning this joint on the basis that it was an oxide joint and not a metal to metal joint. An examination of the joint did not seem to bear out this contention. A series of experiments proved that no difference could be detected between couples having this type of junction and the same couples using a silver soldered joint. The fused junctions have, therefore, not been changed. The fact that the wires may be of small size, No. 22 B. & S. Gage in this case, tends to minimize the effect of radiation to or from the couple, and further the fact that the reading is independent, to a large extent, of the depth of immersion, reduces the liability of error in the determination of the actual temperature of the medium.

*Correction for Radiation Effect.*—It is very difficult to get the true temperature of air flowing over a highly heated surface and a special study must be made of the thermocouples used in the furnace bonnet in order to correct for the radiation effect to which they are subjected. This correction has, however, already been approximately determined by the furnace research staff in the following manner.

A typical leader (Leader No. 2 in Fig. 16) was lagged between the bonnet and the boot with two inches of hair felt, and a series of readings of the temperatures taken at the two points. The hair felt was then removed and a second series of temperature readings taken. In case the reading of the thermocouple in the bonnet had not been affected by radiation, the reading of this couple and the one in the boot with covered leader should have been very nearly the same, since there was practically no heat loss between the two points. The difference shown in the test was 28 deg. F. This difference was attributed to the radiation effect of the hot surfaces on the couple at the bonnet. As the air probably lost some heat between bonnet and boot, although the leader was covered, this difference should have been reduced one or possibly two degrees in estimating the radiation effect. It is certainly as great as $28-2=26$ degrees and probably amounted to 27 deg. F. in the preceding case. The uncovered leader showed a loss of 33 deg. F. by the subtraction of the readings of the couples at the bonnet and boot. Deducting the 26 deg. F., attributed to radiation effect on the couple at the bonnet from this difference in temperature, gives 7 deg. F. as the approximate loss between bonnet and boot in the 4 feet of un-

overed 12-inch leader pipe with an air velocity of 131 feet per minute n the leader.

TABLE 1

TEST FOR RADIATION EFFECT ON BONNET THERMOCOUPLES

(2–11–19)

| | LEADER NO. 2 UNCOVERED | LEADER NO. 2 COVERED |
|---|---|---|
| Bonnet Couple | 194° F. | 195.5° F. |
| Boot Couple | 161 | 167.3 |
| Difference in temperature | 33 | 28.2 |

NOTE.—True loss in uncovered leader, allowing 2-degree drop when covered, gives 33—26.2 =6.8 deg. F.

TEST FOR VELOCITIES IN LEADER NO. 2 UNCOVERED

(2–10–19)

Anemometer reading at register face =169.5 ft. per min.
True velocity at face =225.0 ft. per min.
True velocity in leader $=225 \times \frac{.458}{.785} =131$ ft. per min.
Temperature air leaving register =165° F.

It is also planned to make a study of this radiation effect using ne method suggested in Bureau of Mines Bulletin 145, "Measuring ne Temperature of Gases in Boiler Settings," Kreisinger and Barkley, nd by use of the auxiliary single leader testing plant.

## III. Special Problems Involved in the Measurement of Air Velocities

The second problem is far more difficult of solution than the preceding one and involves the measurement of air flow at the very low velocities or heads occuring in gravity warm-air furnace systems.

It will be evident that no furnace can be tested for efficiency, capacity or rating unless it is possible to determine accurately the amount of air entering the cold air or recirculating inlet and also to measure with equal accuracy the distribution of this air to each of the floors above the furnace.

In order to accomplish the latter object, it is necessary to measure the outflow of heated air at each register face while the test is in progress, and not interfere in any way with the natural operation of the system. The velocities at all these points are small, only a few feet per second at the most, and air measuring instruments which would be quite suitable at higher velocities are either useless, or else subject to serious errors when used at these low rates of flow.

After a great deal of preliminary work in the winter of 1917–1918 it was finally decided to attempt what might be called a "combination scheme" of measurement. In this scheme an instrument which is quite suitable for use at high velocities is used to "check," and give the proper correction factor for the reading which is actually taken by a low velocity instrument best adapted to the conditions to be met in the furnace testing plant.

This "checking" or calibrating work has all been done in two specially designed plants. These plants are constantly available for recalibrating the low velocity instruments at any time, *under the identical conditions as regards air temperature, rate of flow, shape of inlet or outlet, and kind and size of register that exist in the main or auxiliary testing plant.*

*Calibrating Plant for Anemometers Used at Register Faces.*—The calibrating plant for the hot side of the system (Figs. 5 and 6) consists of an electric heater for warming the air to any desired temperature as it is drawn in by a small centrifugal fan. This fan discharges the air through a cylindrical pipe five inches in diameter where the velocity is relatively high so that a Pitot tube may be used as the standard*

*It should be noted that this Pitot tube and air pipe have themselves been checked by the Engineering Experiment Station Staff by still more elaborate and painstaking methods which will be discussed in another bulletin.

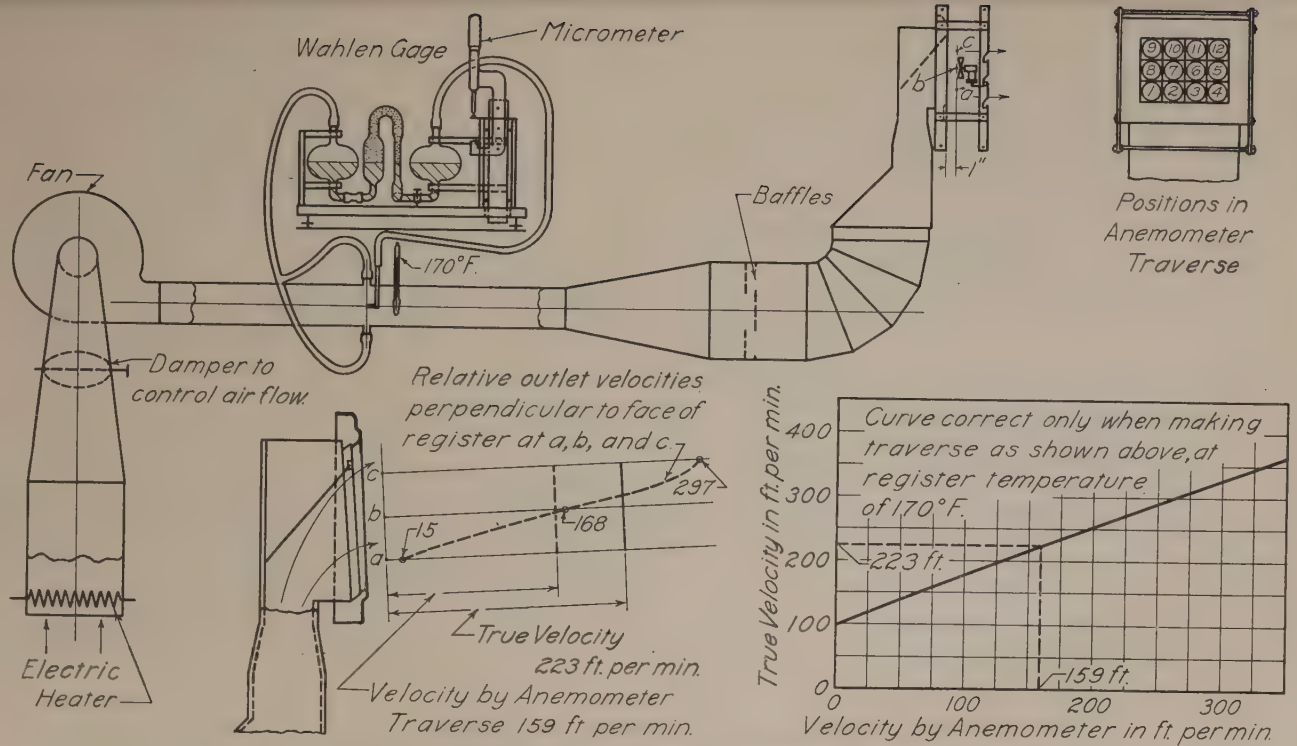



FIG. 6. SECTIONAL VIEW OF PLANT FOR CALIBRATING REGISTER OUTLET ANEMOMETERS, SHOWING DETAILS OF OPERATION

measuring instrument. After the air passes the Pitot tube, it enters an enlarged and well baffled section connecting directly to a standard elbow which turns up into a register box fitted with a sidewall register, as shown in Fig. 5. This register, box and boot are, of course, duplicates of the fittings used in the equipment of the large plant.

It will be apparent that if the exact amount of air passing the Pitot tube is known it is a simple matter to calculate the true volume and velocity of air leaving the register face. With the true velocity known it is now possible to calibrate the low velocity instruments, which are anemometers of the best obtainable type. Suitable cross-head guides are attached to the register frame and so arranged (Fig. 7) that the anemometer attached to the cross-head rod is forced to travel in a uniform and definite manner across the outlet air current at a fixed distance from the register face. As exactly similar guides (Fig. 8) and the same procedure are used on all registers in the main plant this same anemometer is put through exactly the same cycle of operations in running a furnace test.

In making the traverse, an initial reading of the anemometer dial is taken with the instrument in position No. 1 (Fig. 6) and a stop watch is started. The electric heater maintains the desired temperature since it is most essential that the anemometer be calibrated at the temperature existing in the test. At the end of five seconds the instrument is moved to position No. 2 and so on through twelve positions, and the final reading only is then noted. In this way it is possible to average automatically the velocity of the outflowing air which, of course, does not flow out uniformly over the area of the face. Most of the air, as is well known, issues above the center of the register face, as shown in Fig. 6. If the original reading of the dial was 3,820 and the final is 3,979 the instrument *indicates* a velocity of 159 ft. per min. at the register. The anemometer will duplicate this reading within one per cent as often as it is desired to check its performance. By calculation from the reading at the Pitot tube, the *true* velocity was found to be 223 ft. per min., and hence for this particular set of conditions the anemometer reads too low by 64 ft. per min.

It is, of course, evident that it would simplify matters greatly if a series of calibrating tests was run in advance for each anemometer. A series of curves could then be drawn (Fig. 6) from which *true* velocities at any register temperature could be found as soon as the velocity *indicated* by the anemometer on any test was known. This calibration has been done, entailing months of painstaking and exacting measure-

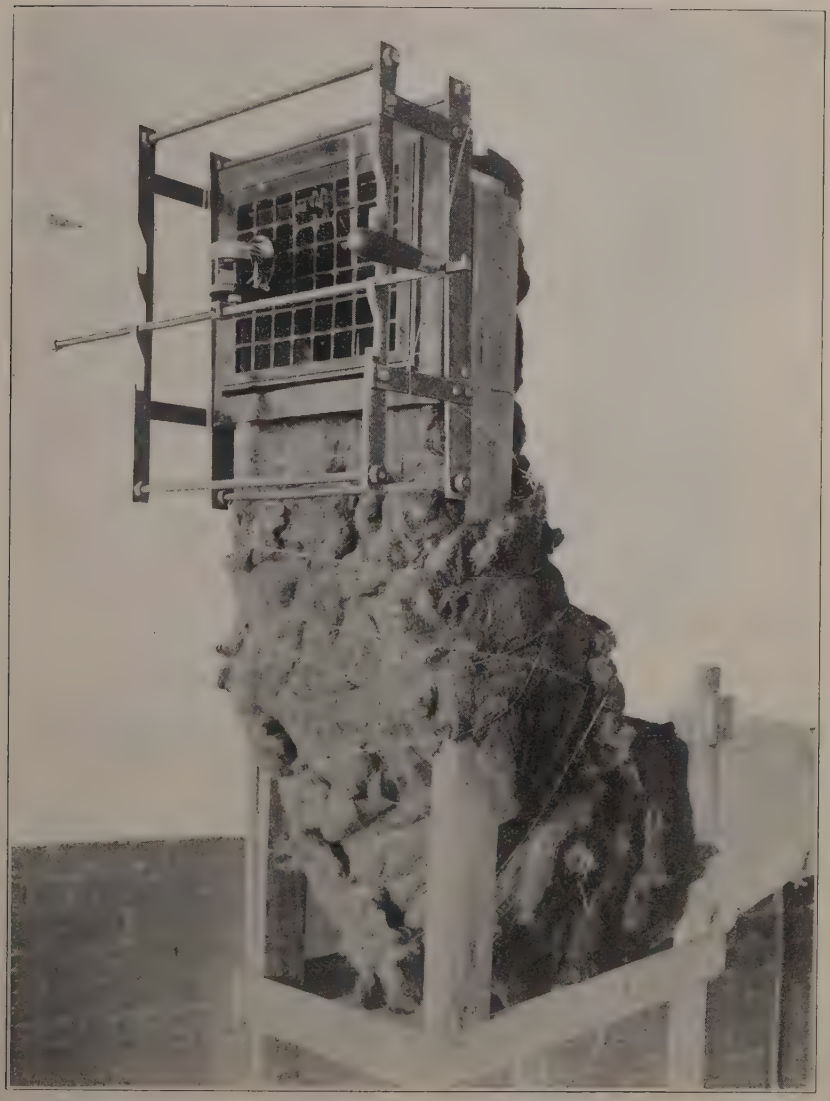


FIG. 7. TYPICAL ARRANGEMENT AT REGISTER FACE IN CALIBRATING PLANT FOR MAKING ANEMOMETER TRAVERSE

Fig. 8. Method of Making Anemometer Traverse at Register Faces on Main Plant

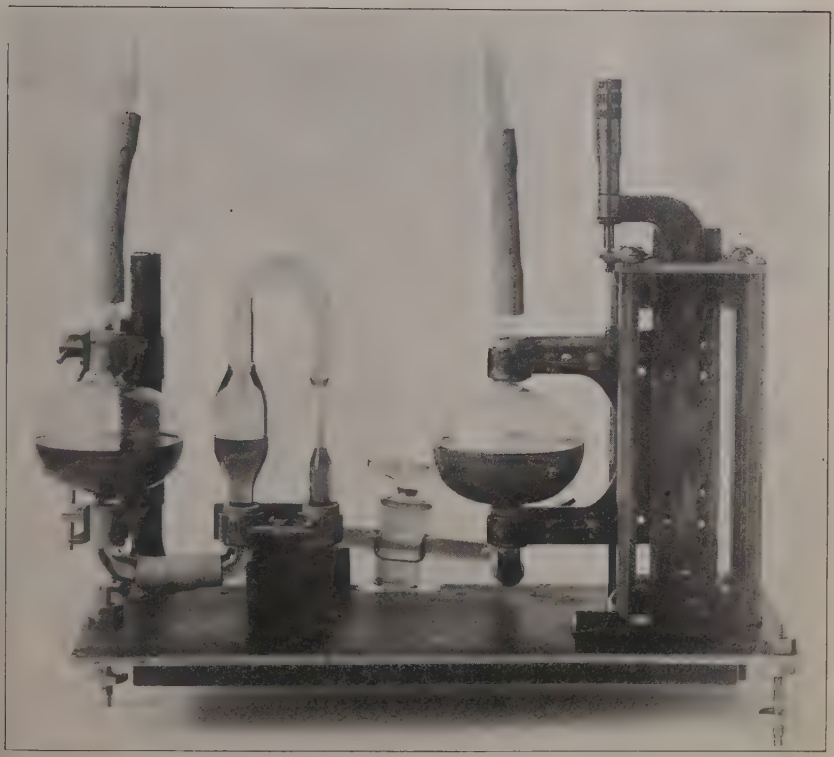


Fig. 9. The Wahlen Gage, Sensitive and Accurate to 0.0001 inch
Alcohol

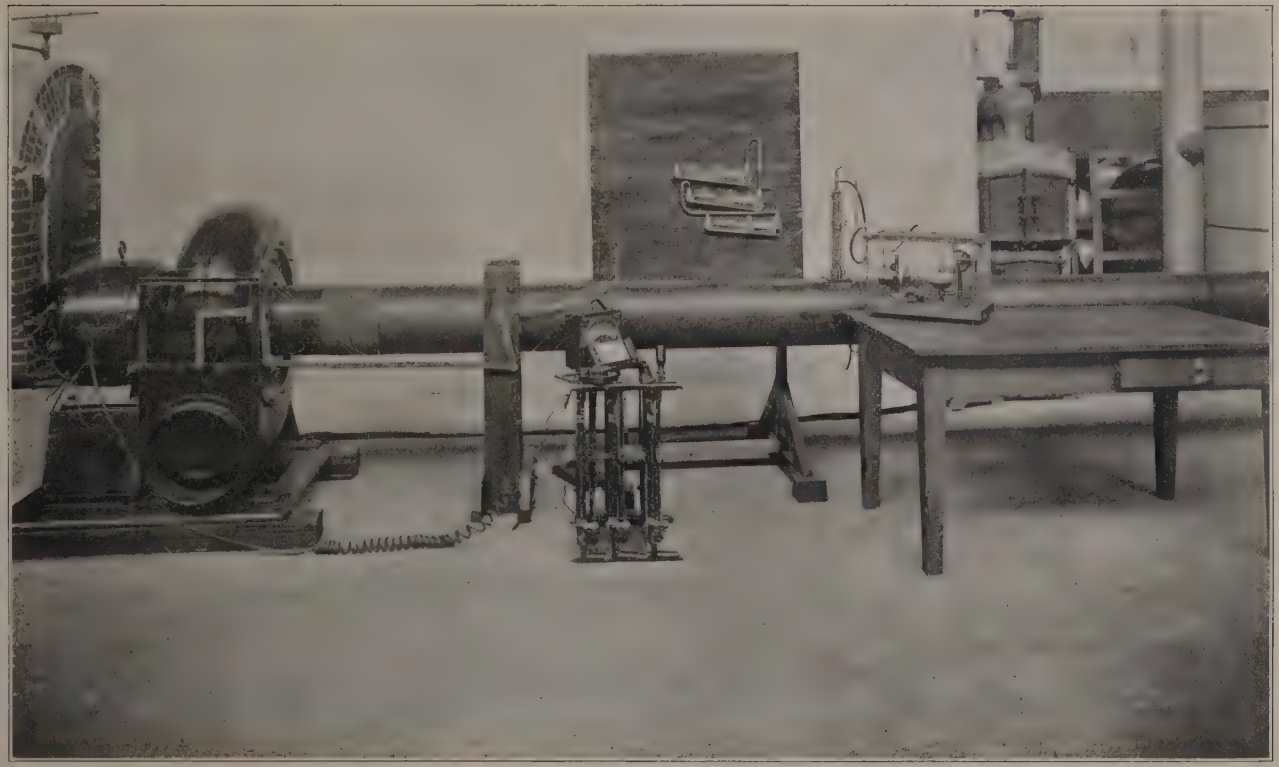


Fig. 10. The Calibrating Plant for the Inlet Side of the System Showing the Wahlen Gage in Use

ments. The same sort of calibration data had to be secured for the cool air inlet anemometers, as well as for those used on the warm air outlets. It is most important to have the calibrating plant constantly available for checking the performance of any anemometer during any test.

*The Wahlen Gage.*—It was this calibrating work* that probably developed the greatest difficulties which have been encountered. Every possible refinement of measurement was resorted to without complete success until F. G. Wahlen (detailed to this work from the Experiment Station Staff) finally developed a remarkable gage (Fig. 9) so sensitive and accurate that it would measure a pressure head of less than $\frac{1}{10000}$ of an inch of water, and respond instantly to the slightest fluctuation in pressure. This equipment is a distinct addition to such precision instruments as are available for measuring low-pressure heads.

This gage† made it possible to duplicate readily readings with the Pitot tube used for checking the anemometer to within one per cent.

The essential features of the gage are clearly shown in the illustration, from which it will be seen that a rigid base set on leveling screws is used to support two large glass bulbs which are in communication with each other through an inverted U tube of peculiar shape. The left hand bulb is rigidly attached to the base frame, but the right hand bulb moves vertically up or down with the carriage to which it is attached. The motion of this carriage is controlled by frictionless rollers which eliminate all back lash or side sway. This movement is under the positive control of a micrometer screw, reading to 0.001 inch direct, and takes place with a slight swivelling action of the joints in the right hand connector. Pressures are communicated to the two bulbs through the flexible connectors on the top of each.

Alcohol (0.8195) about half fills the bulbs and the U tube, and a little aniline dye gives a distinctive red color. The upper part of the U tube is completely filled with a clear turpentine and ligroin mixture (0.8100) so made up that its specific gravity is 0.0095 less than the density of the colored alcohol.

In operation (Figs. 6, 10 and 19), the gage is first balanced at zero with both pressure connections open. This is easily done by bringing the meniscus in the constricted side of the U tube to a reference line engraved near the center of the tube and then reading the micrometer.

---

*Prof. S. L. Simmering devoted practically all his time to this problem until April 1, 1919, when he resigned to accept a position at the University of Colorado.

†See a more detailed description of this instrument in a separate paper entitled the "Illinois Micromanometer" by F. G. Wahlen.

This zero setting can be accomplished (without using a microscope) to within 0.0001 of an inch of alcohol, equivalent to about 0.00008 of an inch of water. Pressure connections are then made and the movable carriage and its liquid bulb so manipulated that the meniscus is brought back to the reference line on the U tube and the micrometer read again. In fact, by proper use of the stop cock in the connecting arm of the gage this meniscus is never allowed to move out of the constricted tube at all. The difference between the two micrometer readings when multiplied by the density of the alcohol gives the pressure head in inches of water. A final zero reading is always taken and must check to 0.0002 of an inch with the original zero. As the density of the alcohol varies with its temperature a density-temperature calibration curve is used, and the gage is enclosed in a glass case as shown in Figs. 10 and 19 where it is seen in use.

It will be evident from the preceding statement that as there has been no movement of the measuring liquid no corrections are necessary for capillarity, viscosity, variations in bore of tubes, or conditions of glass surface. The sensitiveness of the gage depends (1) upon the relation between the areas of the constricted tube and the large cross section of the bulbs, (2) upon the viscosity characteristics of the two liquids and the small density differential, and (3) upon the fact that the constricted part of the U tube is very short. All other connections are large and free. A standard machinist's precision micrometer forms the measuring element of the gage which is accurate within the range of measurement.

*Calibrating Plant for Anemometers Used at Inlet.*—The calibrating plant (Fig. 10) for the cold side of the system consists of a cool air inlet opening of exactly the same size and arrangement (Fig. 11) as that used on the furnace plant itself (Fig. 12). This opening is equipped with crosshead guides and traverse rod for carrying the anemometer across the face. This large duct then tapers (Fig. 1, see lower left-hand corner) to connect with a steel pipe 10 inches in diameter in which a Pitot tube is placed for checking the actual weight of air flowing. A large fan at the outlet end is arranged with variable speed control to handle such volumes of air as correspond to the amounts entering the furnace plant under the various test conditions. In this inlet calibrating plant the *indicated* and *true* velocities of the inlet air are obtained in a manner similar to that already described, and suitable calibration curves have been drawn. The Wahlen gage has proved as essential here for accuracy and refinement of readings with the Pitot tube as in

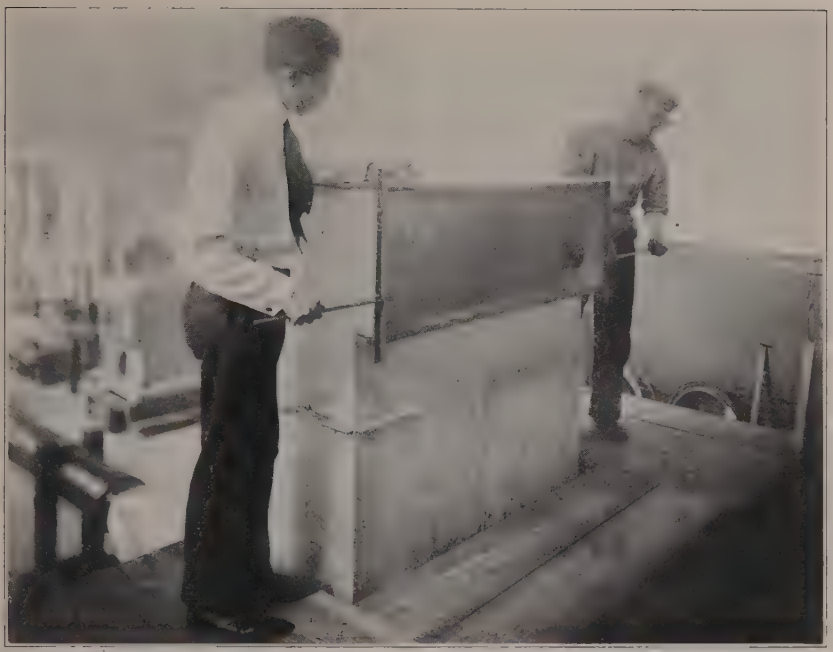


FIG. 11. METHOD OF MAKING TRAVERSE AT THE INLET OPENING OF THE CALIBRATING PLANT FOR MEASURING RECIRCULATED AIR

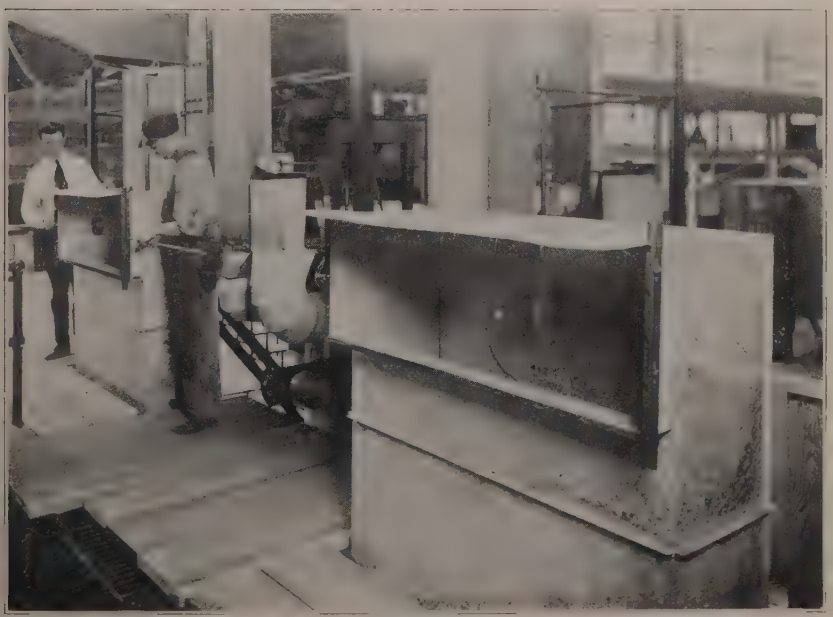
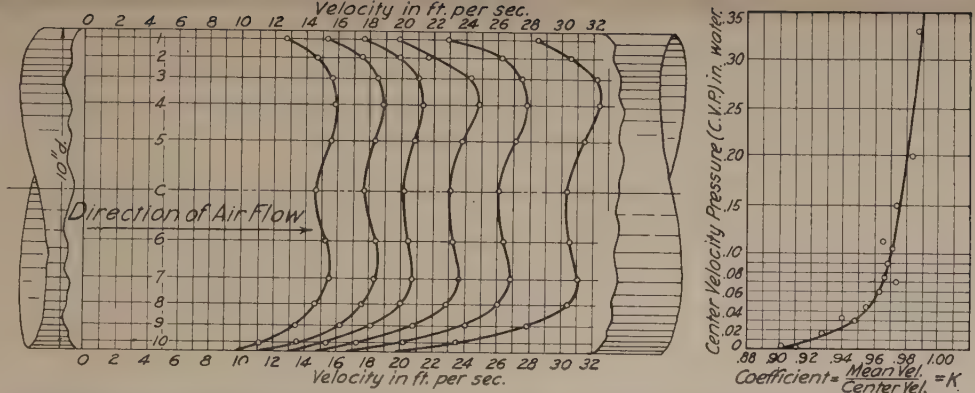


FIG. 12. MEASURING THE AIR ENTERING THE FURNACE AT THE INLET OPENING WHICH IS AN EXACT DUPLICATE OF THE OPENING ON THE CALIBRATING PLANT IN THE RIGHT FOREGROUND

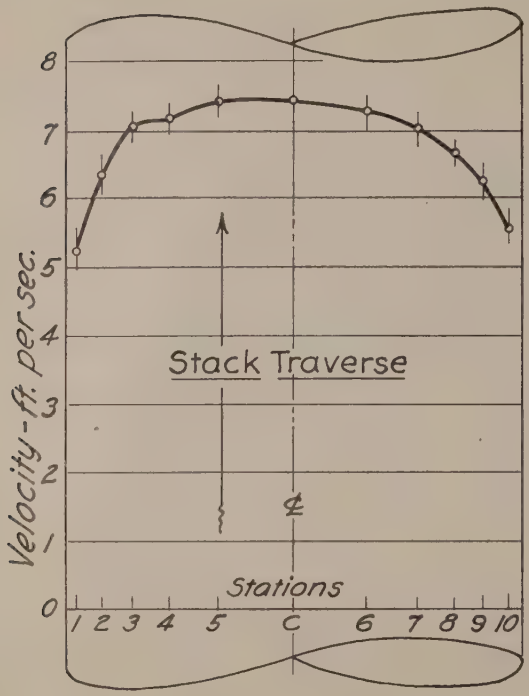



| Position Pitot | C.V.P. | Velocity | C.V.P. | Velocity | C.V.P. | Velocity | C.V.P. | Velocity | C.V.P. | Velocity | C.V.P. | Velocity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .0319 | 12.68 | .0514 | 15.30 | .0681 | 17.60 | .0871 | 19.90 | .1158 | 22.92 | .1577 | 28.5 |
| 2 | .0426 | 14.67 | .0675 | 17.53 | .0875 | 19.94 | .1156 | 21.60 | .1521 | 26.30 | .2057 | 30.7 |
| 3 | .0483 | 15.60 | .0755 | 18.54 | .0970 | 21.00 | .1295 | 24.30 | .1673 | 27.55 | .2268 | 32.2 |
| 4 | .0500 | 15.88 | .0785 | 18.90 | .0998 | 21.30 | .1350 | 24.80 | .1700 | 27.80 | .2296 | 32.4 |
| 5 | .0484 | 15.60 | .0744 | 18.41 | .0961 | 20.90 | .1257 | 23.85 | .1624 | 27.20 | .2163 | 31.5 |
| C | .0451 | 14.51 | .0691 | 17.72 | .0891 | 20.17 | .1170 | 23.10 | .1507 | 26.22 | .2016 | 30.4 |
| 6 | .0459 | 15.22 | .0745 | 18.41 | .0915 | 20.40 | .1194 | 23.30 | .1539 | 26.40 | .2052 | 30.6 |
| 7 | .0476 | 15.50 | .0743 | 18.40 | .0937 | 20.63 | .1234 | 23.70 | .1586 | 26.88 | .2116 | 31.1 |
| 8 | .0426 | 14.67 | .0682 | 17.65 | .0882 | 20.04 | .1155 | 22.90 | .1495 | 26.10 | .2023 | 30.4 |
| 9 | .0352 | 13.32 | .0572 | 16.12 | .0728 | 18.20 | .0957 | 20.80 | .1272 | 24.08 | .1700 | 27.9 |
| 10 | .0245 | 11.10 | .0397 | 13.45 | .0515 | 15.31 | .0671 | 17.32 | .0897 | 20.20 | .1202 | 23.5 |

TABLE OF CENTER VELOCITY PRESSURES, IN INCHES OF WATER, & VELOCITIES, FT./SEC.

Note: Quantity of Air per min. = Center Velocity × K × 50 × Area of Pipe, sq. ft.

FIG. 13. VELOCITY CURVES FROM THE INLET CALIBRATING PLANT, SHOWING HOW CENTER COEFFICIENT VARIES WITH THE VELOCITY OF FLOW. BASED ON READINGS BY WAHLEN GAGE




Note: Round pipes are divided into five concentric rings of equal area. Stations are so taken as to give the average velocity of each air ring.

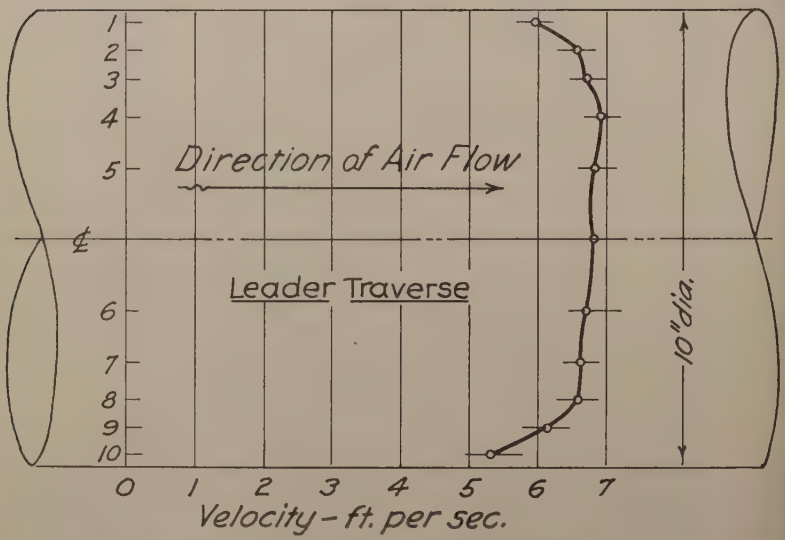



FIG. 14. VELOCITY CURVES FROM A LEADER AND ALSO FROM A STACK, SHOWING CHARACTER OF AIR FLOW THROUGH SAME

the previous calibrating work. In carrying out this calibrating work, it has been found necessary always to make a traverse of both the 5-inch and the 10-inch pipes in order to get the average velocity of air flow through the pipe at the section where the velocity pressures are measured by the Pitot tube. This variation in velocity across the diameter is large even for a fixed quantity of air passing through the pipe. The relation between the average velocity reading and the center velocity reading, $\frac{Vm}{Vc}=K$, changes, moreover, with a change in the quantity of air passing through the pipe as shown in the curves of Fig. 13 taken from the 10-inch pipe. Curves taken from a traverse of a leader (Fig. 14) on the auxiliary furnace plant show this same variation in velocity while those taken from a traverse near the head of a round stack (Fig. 14) also on the auxiliary plant show an even greater variation. The center reading is proportionately much higher, in the latter case, than the average velocity reading. The curves in Fig. 14 are merely submitted as illustrative of the sensitiveness of the Wahlen gage at low velocities and show its usefulness in studying air flow in leaders and stacks and even through the furnace casing itself. At some later period in the investigation such a study should be made, but it is the present purpose to test first the furnace and the plant as a whole.

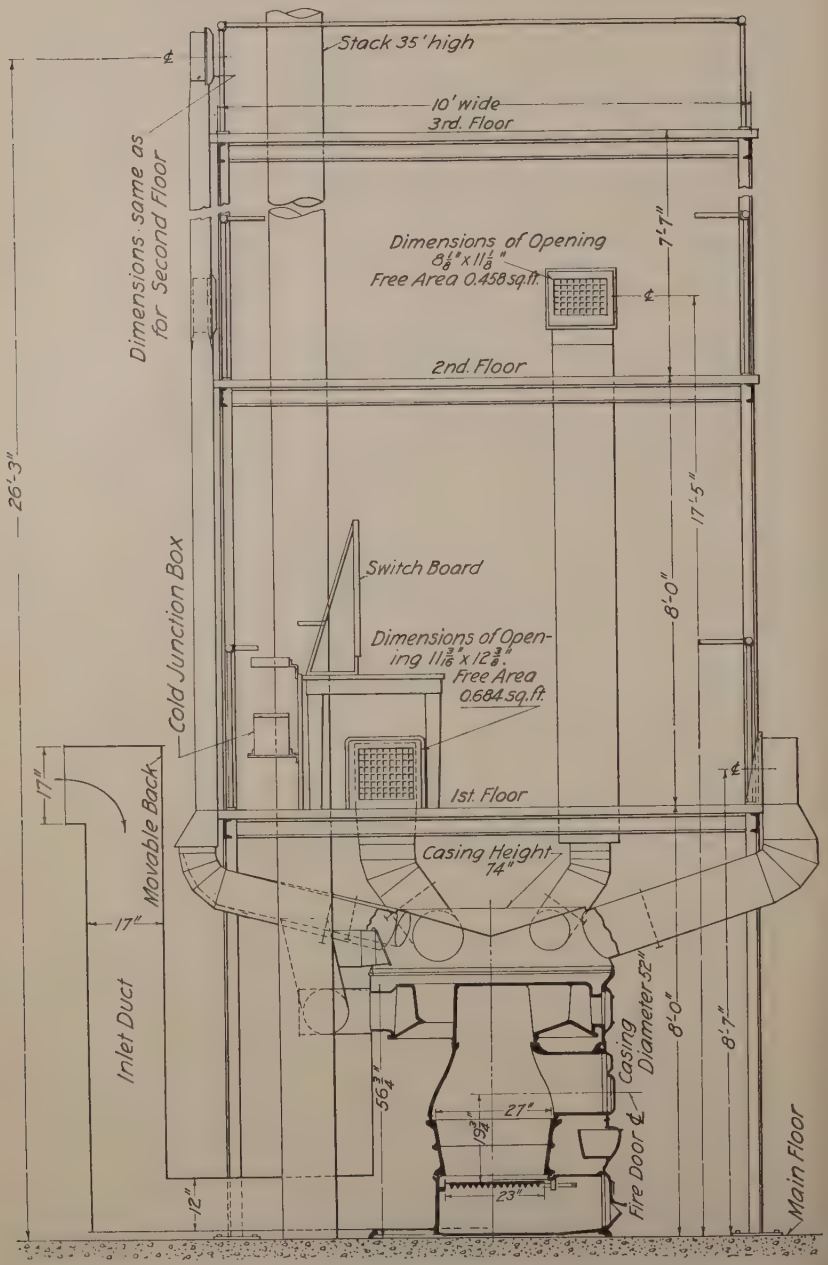



FIG. 15. SECTIONAL ELEVATION OF FURNACE TESTING PLANT

## IV. The Main Plant

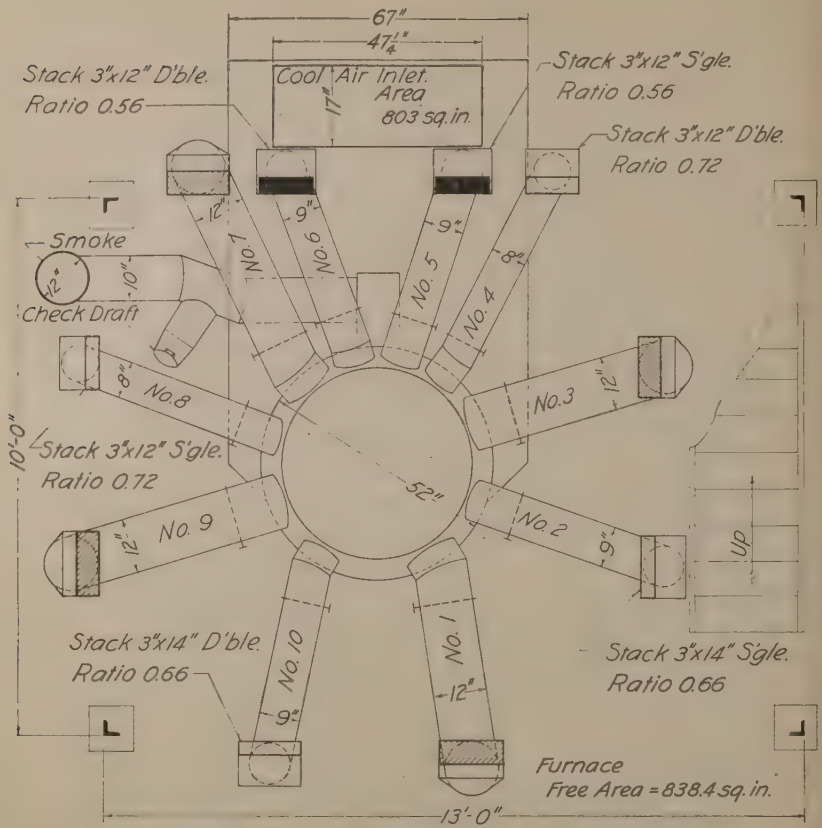
The general view (Fig. 1) of the present (April-May, 1919) main plant* shows a three-story steel structure erected in the Mechanical Engineering Laboratory. This structure merely serves as the working skeleton of a house and carries the stacks and registers which run to the various floors. All important dimensions are given in the sectional elevation and plan (Figs. 15 and 16), which show the equipment in use on May 1, 1919. A ten-leader plant is being used at present and all stacks have been cased in to simulate furred wall conditions. One of the four stacks to the second floor and one of the two stacks running to the third floor are single, but all other stacks are double wall with 5/16-inch air space. The single stacks were made 3-inch deep instead of 3½-inch in order to make them comparable with double wall stacks.

The side view of the furnace and leader system (Fig. 2) shows the recirculating duct and the crosshead guide at the inlet to the duct. In the right foreground is a Uehling $CO_2$ outfit for taking a continuous $CO_2$ record on all tests. A sample record is given in Fig. 17 and the performance of this instrument is checked periodically by a portable Orsat apparatus. This view also shows an observer reading temperatures at the thermocouple switchboard.

*Results Obtained from Main Plant.*—It has already been stated that as this is a report of progress, more or less summarized statements will be made including such typical test data as will best illustrate the scope and character of the work thus far accomplished. The first and second objects of the investigation have already been given as (1) the determination of efficiency and capacity of warm air furnaces under conditions similar to those in an actual installation, and (2) the fixing of proper methods of rating furnaces. These two objects are so dependent on each other that it is almost impossible to deal with them separately. Fairly definite conclusions must be reached concerning the *basis* for ratings before tests for efficiency and capacity can be conducted.

The following summary of test data (Table 2) from a series of seven runs on the main plant between March 14 and April 23, 1919, will

*The original main plant was found to have entirely too great a leader and stack area for the free area of the furnace and the second and third floor runs were reduced in size to the dimensions shown in Fig. 16.




| | Leaders | | | Stacks | | Registers | |
|---|---|---|---|---|---|---|---|
| | No. | Size | Area | Dimensions | Type | Dimensions | Free Area |
| 1st. Floor | 1 | 12 in. | 113 sq.in | —— | Asbestos Covered | $11\frac{3}{16}$ in x $12\frac{3}{8}$ in | 0.684 sq ft. |
| | 3 | 12 in | 113 sq.in | —— | | " " | " |
| | 7 | 12 in | 113 sq.in | —— | | " " | " |
| | 9 | 12 in. | 113 sq.in. | —— | | " " | " |
| 2nd. Floor | 2 | 9 in. | 64 sq.in. | 3 in. x 14 in. | S'gle. | $8\frac{1}{8}$ in x $11\frac{1}{8}$ in. | 0.458 sq.ft. |
| | 4 | 8 in. | 50 sq.in. | 3 in. x 12 in | D'ble. | " " | " |
| | 8 | 8 in. | 50 sq.in | 3 in. x 12 in. | S'gle. | " " | " |
| | 10 | 9 in. | 64 sq.in. | 3 in. x 14 in. | D'ble | " " | " |
| 3rd Floor | 5 | 9 in. | 64 sq.in. | 3 in. x 12 in. | S'gle | " " | " |
| | 6 | 9 in. | 64 sq.in. | 3 in. x 12 in. | D'ble | " " | " |
| Leader Area: 1st. Fl. 452 sq.in., 2nd 228 sq.in., 3rd. 128 sq in. Total 808 sq. in. | | | | | | | |
| Percent Leader Area: 1st. Fl. 55.9, 2nd. 28.2, 3rd. 15.8. | | | | | | | |

FIG. 16. FLOOR PLAN AND DIMENSION TABLE FOR FURNACE TESTING PLANT

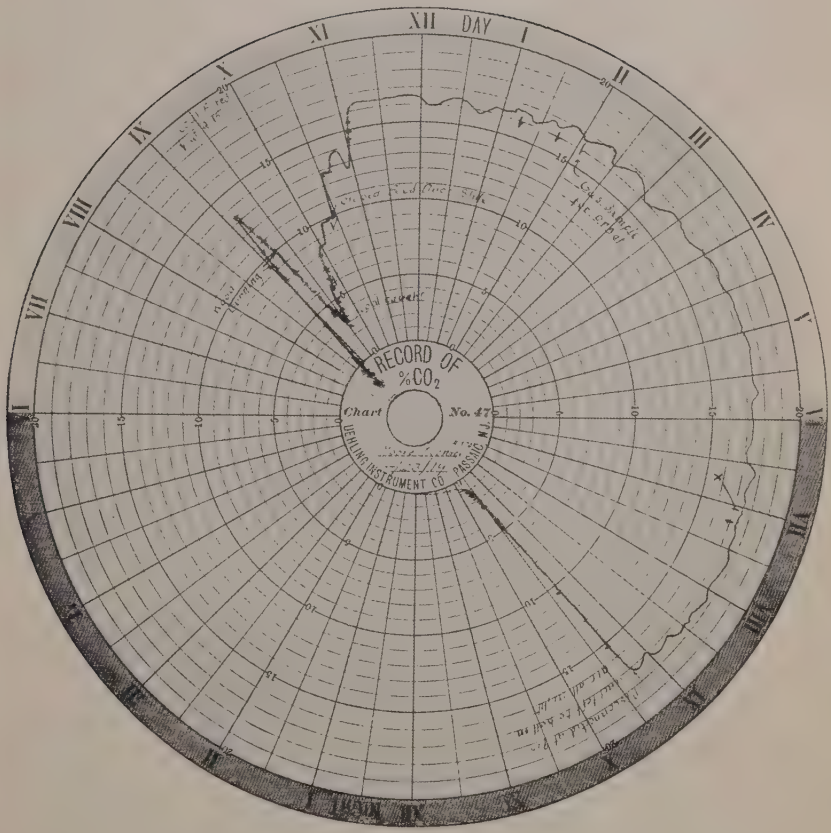



FIG. 17. SAMPLE $CO_2$ RECORD TAKEN BY THE UEHLING $CO_2$ RECORDER FROM TEST OF APRIL 23, 1919

illustrate this interdependency previously noted and will show how the conditions of rating affect capacity and likewise efficiency.

TABLE 2

SUMMARY OF SEVEN TESTS ON THE MAIN PLANT SHOWING EFFECT OF REGISTER TEMPERATURES ON CAPACITY OF FURNACE AND LEADERS

WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

Date 3-14 to 4-23-19
Name Entire Staff

Subject Summary of Seven Tests Showing Effect of Register Temperature on Capacity.

Fuel: Stove size anthracite, in solid fire pot. No draft over 0.2" of water.

| No. | Time | Test No. | Average Temperature Rise and Register Temperature. † 1st. | 2nd. | 3rd. | Average Leader Vel. in ft. per min., and per cent Weight per floor. 1st. | 2nd. | 3rd. | Average B.t.u. Available for Heating above 70° per sq. in. Leader. 1st. | 2nd. | 3rd. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3-14-19 | 1 | 78.2 | 70.0 | 81.0 | 118.5 | 215 | 264 | 52 | 85 | 121 |
| 2 | | | 143.2 | 135.0 | 146.0 | 39.6% | 35.8% | 24.6% | | | |
| 3 | Av. Reg. Temp. | | | 141.4 | | | | | | | |
| 4 | | | | | | | | | | | |
| 5 | 4-17-19 | 2 | 75.3 | 72.4 | 81.0 | 118.0 | 219 | 268 | 50 | 89 | 122 |
| 6 | | | 140.3 | 137.4 | 146.0 | 39.3% | 36.2 | 24.4 | | | |
| 7 | Av. Reg. Temp. | | | 141.2 | | | | | | | |
| 8 | | | | | | | | | | | |
| 9 | 4-23-19 | 3 | 88.8 | 78.6 | 89.5 | 131 | 226 | 274 | 68 | 107 | 144 |
| 10 | | | 153.8 | 143.6 | 154.5 | 41.9% | 36.2 | 21.9 | | | |
| 11 | Av. Reg. Temp. | | | 149.8 | | | | | | | |
| 12 | | | | | | | | | | | |
| 13 | 4-18-19 | 4 | 105.3 | 95.4 | 101.9 | 148 | 245 | 304 | 85 | 134 | 175 |
| 14 | | | 170.3 | 160.4 | 166.9 | 41.8% | 34.9 | 23.3 | | | |
| 15 | Av. Reg. Temp. | | | 165.9 | | | | | | | |
| 16 | | | | | | | | | | | |
| 17 | 4-21-19 | 5 | 113.5 | 105.0 | 114.0 | 159 | 252 | 315 | 103 | 153 | 204 |
| 18 | | | 178.5 | 170.0 | 179.0 | 42.8% | 34.1 | 23.1 | | | |
| 19 | Av. Reg. Temp. | | | 175.8 | | | | | | | |
| 20 | | | | | | | | | | | |
| 21 | 4-21-19 | 6 | 132.6 | 115.8 | 132.4 | 183 | 268 | 331 | 134 | 168 | 243 |
| 22 | | | 197.6 | 180.5 | 197.4 | 44.6% | 33.0 | 22.4 | | | |
| 23 | Av. Reg. Temp. | | | 191.9 | | | | | | | |
| 24 | | | | | | | | | | | |
| 25 | 4-21-19 | 7 | 119.3 | 105.3 | 114.1 | 165.5 | 224 | 246 | 68 | 107 | 144 |
| 26 | | | 184.3 | 170.3 | 179.1 | 47.6% | 32.4 | 20.0 | | | |
| 27 | Av. Reg. Temp. | | | 177.9 | | | | | | | |
| 28 | | | | | | Actual & Relative Leader Area | | | | | |
| 29 | | | | | | 452 sq in | 228 | 128 | | | |
| 30 | | | | | | 56.0% | 28.2% | 15.8% | | | |

Remarks: All dampers wide open except in Test No. 7. For dimensions of leaders, stacks and registers, and plant layout see Fig. 16 and Table therewith.
† Register temperatures based on air entering furnace at 65° F.

The tests will be referred to by number, and were run to determine to what extent variations in the outlet air temperatures at the registers affect the rating of a furnace when installed in a complete plant. The average outlet temperatures were 141.2, 149.8, 165.9, 175.8, 177.9, and 191.9 deg. F. based on air entering furnace at 65 deg. F. It is entirely possible to maintain register temperatures constant within a 5-degree range on any test. Tests No. 1 and No. 2 were run under the same conditions as checks on each other, and have both been submitted to show how nearly it is possible to duplicate runs on the plant at different dates. The data from No. 2 will be used in the comparisons considered in the following discussion. All tests were run with the plant as shown in Figs. 15 and 16.

*Effect of Register Temperature on Leader Pipe Capacity.*—The first thing discovered from a survey of these data was that a square inch of leader pipe area in a first floor leader has far less heating and air-carrying value than in a second or third floor leader as installed. In test No. 2 (Aver. reg. temp. 141.2 deg. F.), for example, a square inch of leader to first floor carries 50 B. t. u. per hour available for heating above 70 deg. F., and for a third floor leader this value rises to 122 B. t. u. per hour making *an increase* of 144 per cent. For the second floor the B. t. u. per sq. in. is 89, or *an increase* of 70 per cent.

A comparison of leader velocities for this same test shows 118 ft. per minute for the first floor, and 268 ft. per minute for the third floor, which is an increase of 127 per cent. For the second floor the increase in velocity is 85 per cent.

A still more significant discovery was made by comparing tests No. 2 (Aver. reg. temp. 141.2 deg. F.) and No. 6 (Aver. reg. temp. 191.9 deg. F.) from which it was found that a square inch of first floor leader has increased its capacity in available heating value above 70 deg. F. from 50 B. t. u. to 134 B. t. u. per hour, *a gain of 170 per cent.* For a second floor leader this value increased from 89 to 168 B. t. u. per hour or *a gain of 89 per cent*, and for a third floor leader this value jumps from 122 B. t. u. to 243 B. t. u. or *a gain of 99 per cent.* It should be noted that these gains are very large, much larger than the increase in velocities through these leaders.

If a comparison of velocities in the leaders for these same two tests is made, it is found that the first floor leader velocities have increased from 118 to 183 ft. per min., a gain of 55 per cent. In the case of second floor leaders, the velocities have increased from 219 to 268 ft. per min.,

a gain of 22 per cent, and for the third floor leaders the velocities show an increase of from 268 to 331 ft. per min., a gain of 24 per cent.

Further comparisons of this kind at other register temperatures may be readily made by reference to the data in the table.

It should also be noted that the distribution of the air by weight to the various floors has changed with the increasing register temperatures. In Test No. 2 the relation was: First floor = 39.3 per cent, second = 36.2 per cent and third = 24.4 per cent while in test No. 6 it changed to: First floor = 44.6 per cent, second = 32.4 per cent and third = 21.9 per cent. In test No. 7 (Aver. reg. temp. 177.9 deg. F.) an attempt was made to increase the velocity and heating value per square inch of leader pipe supplying the first floor by dampering the second and third floor leaders. This resulted in a distribution of 47.6 per cent of the air to first floor, 32.4 per cent to second, and 20 per cent to third. By reference to test No. 5 (Aver. reg. temp. 175.8 deg. F.) which is most nearly comparable, it will be seen that the gain in velocity (Table 3) and in B. t. u. per square inch of leader pipe to first floor was small and much more than offset by the reduction in these quantities for the second and third floors.

TABLE 3

EFFECT OF DAMPERING SECOND AND THIRD FLOOR LEADERS TO INCREASE CAPACITY OF FIRST FLOOR LEADERS

| Test No. | Vel. ft. per min. | | | B. t. u. per sq. in. | | | Aver. Reg. Temp. |
|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 1st | 2nd | 3rd | |
| 5 | 159.0 | 252 | 315 | 103 | 153 | 204 | 175.8 |
| 7 | 165.5 | 224 | 246 | 111 | 137 | 160 | 177.9 |
| Gain | 6.5 | | | 8 | | | |
| Reduction | | 28 | 31 | | 16 | 44 | |

It is, therefore, quite evident that the practice of dampering leaders to upper floors as a result of poor design immediately cuts down the total capacity of a plant. The slight gain in heating effect on the first floor is accomplished at a serious sacrifice both in plant capacity and efficiency. This problem is worthy of further investigation at the first opportunity.

The great significance of the data developed by these seven tests can hardly be overestimated and is the first important result of this investigation. It affects not only the basis for rating furnaces and designing furnace heating systems, but establishes very definite limits

for rating and capacity tests. It is a very simple matter to show that a furnace heating plant in a two or three story house in order to be entirely successful in the coldest weather must have a very large proportion of its leader capacity devoted to supplying the first floor if the register temperatures are to be kept as low as 150 deg. F. In fact, attempts to apply these data to an actual design worked out by W. E. Pratt with the given temperature limitation show that prohibitive leader sizes will result. A more satisfactory basis for design and also for rating requires a register temperature between 175 and 185 deg. F., which has been used by Mr. Pratt in applying these data to a typical house heating design problem to be presented at the June meeting of the Association. A summarized statement concerning the effect of these temperatures on a furnace heating design problem will be found in Section VII of this Bulletin.

It, therefore, appears desirable and necessary to recommend on the basis of the data thus far obtained that in rating furnaces in square inches of leader pipe area the leaders to first floors should be limited

TABLE 4

CHEMICAL ANALYSIS OF THE ANTHRACITE COAL USED IN THESE TESTS

ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
Report of Chemical Analysis by Prof. S. W. Parr and J. M. Lindgren
April 30, 1919
Chemical Laboratory *No. 10675*
Special Marks *Scranton Anthracite*[1] *Warm-Air Furnace Trial*

| Proximate Analysis of Coal | Per cent for Coal as Fired |
|---|---|
| Fixed carbon | 78.98 |
| Volatile matter | 6.19 |
| Moisture | 1.44 |
| Ash | 13.39 |

| Ultimate Analysis of Coal | Per cent for Coal as Fired |
|---|---|
| Carbon (C) | 79.52 |
| Hydrogen (H) | 2.43 |
| Oxygen (O) | 1.68 |
| Nitrogen (N) | 0.75 |
| Sulphur (S) | 0.81 |
| Ash | 13.39 |
| Moisture at 105° C. | 1.44 |

| Calorific Value—B. t. u. | |
|---|---|
| By Oxygen Calorimeter per pound of Air Dry Coal | 127.91 |

[1]After rejecting one shipment of hard coal it was finally decided to store 30 tons of the above coal as a uniform test fuel for running all tests.

to 100–115 B. t. u. per square inch, to second floors to 160–180 B. t. u. per square inch, and to third floors to 195-215 B. t. u. per square inch, when the average register temperature is approximately from 175 to 185 deg. F. It will also be apparent that for most of the heating season a lower register temperature, probably in the neighborhood of 150 deg. F., will be quite satisfactory, and there may be occasional days when the air at the registers must be even above 175 deg. F. for short periods as it would be poor economy to design for the coldest day that was ever recorded in a certain locality.

*Efficiency and Capacity Tests.*—The question of testing furnaces for efficiency and capacity may now be considered with some degree of definiteness, and it is evident that register temperatures must be made the controlling factor if the data are to prove applicable in practice. These tests should, of course, cover a reasonable range of register temperatures, as from 120 to 190 deg. F., in order to show at what register temperature a given furnace is most efficient. It should be noted here that this probably will not be the temperature at which the furnace is rated for capacity, and it is not necessary that it should be.

In addition to the preceding limitation, it was decided to observe the following conditions and procedure in this first series of tests:

(1) The fuel is to be stove size anthracite with an ash content of less than 14 per cent for dry coal.

(2) The chimney draft must not exceed 0.2 inches of water at any time during a test.

(3) The furnace is always to be started with weight of wood equivalent to 10 per cent of its coal capacity and warmed up for fifteen minutes.

(4) The test is to start at the expiration of the fifteen minute preliminary period, with one-third of the total fuel charge (based on firepot capacity).

(5) The second firing of the second one-third of the fuel charge is to be made at the end of fifteen minutes from start of test.

(6) The third firing of the final one-third of the fuel charge is to be made at the end of thirty minutes from start of test. After this firing the fire must not be touched.

(7) At the end of the test, which must not consume more than 80 per cent of the total fuel charge, the fire is to be quenched with water and drawn, and the ashpit cleaned.

(8) The residue is to be weighed and its moisture content and heat value determined.

(9) The composition of the coal used is as shown in Table 4.

The results of five complete tests, on the main plant showing variations in efficiency with register temperatures, are given herewith (Table 5), and a summary sheet of the first test of April 23, 1919, is reproduced (Table 6) as well as a graphical $CO_2$ record (Fig. 17) from the Uehling $CO_2$ apparatus. A consideration of the results from the first three tests shows that the so-called radiation loss from the double casing and the bonnet of the furnace was high. If the first test No. A-1 is taken, it appears that in a 12-hour run with an average equivalent register temperature of 149.8 deg. above a 65 deg. F. inlet temperature the heat put into the air passing through the furnace before it left the bonnet amounted to 54 per cent of the total heat in the coal burned.

TABLE 5

SUMMARY OF FIVE COMPLETE PLANT TESTS FOR EFFICIENCY AND CAPACITY OF FURNACE

| ITEM | Uncovered Casing | | | Lagged all over | Lagged above Middle Ring |
|---|---|---|---|---|---|
| | A-1 | A-2 | A-3 | Q-4 | A-5 |
| Date of test | 4-23-19 | 4-30-19 | 5-1-19 | 5-3-19 | 5-9-19 |
| Duration in hours | 12.0 | 12.0 | 9.5 | 12.0 | 12.0 |
| Ave. Temp. at Register Faces, deg. F. (actual) | 169.4 | 182.5 | 197.7 | 188.3 | 175.4 |
| Ave. Temp. at Register Faces, deg. F. (above 65 deg. F.) | 149.8 | 167.5 | 186.1 | 168.8 | 167.0 |
| Total weight of coal fired, lb. | 256.0 | 255.0 | 255.0 | 255.0 | 255.0 |
| Total weight of refuse out, lb. | 141.5 | 107.3 | 108.5 | 112.5 | 114.5 |
| Total equivalent coal in refuse, lb. | 110.0 | 86.2 | 86.6 | 90.0 | 91.1 |
| Total weight of coal burned, lb. | 146.0 | 168.8 | 168.4 | 165.0 | 163.9 |
| Rate of combustion, lbs. per sq. ft. | 4.23 | 4.89 | 6.16 | 4.77 | 4.74 |
| Average chimney draft, inches water | 0.054 | 0.054 | 0.079 | 0.053 | 0.058 |
| B.t.u. per lb. coal as received | 12791 | 12791 | 12791 | 12791 | 12791 |
| B.t.u. per lb. refuse at end of test | 10023 | 10260 | 10200 | 10216 | 10180 |
| Heat developed by coal burned per hr., B.t.u. | 155,500 | 179,800 | 226,500 | 175,900 | 174,700 |
| Ave. temp. of air at inlet, deg. F. | 84.6 | 80.0 | 76.6 | 84.5 | 73.4 |
| Ave. bonnet temp., deg. F. (actual) | 181.5 | 194.8 | 210.7 | 200.2 | 188.0 |
| Ave. temp. rise, inlet to bonnet, deg. F. | 97.0 | 114.8 | 134.1 | 115.7 | 114.6 |
| Ave. bonnet temp., deg. F. (above 65 deg. F.) | 172.0 | 179.8 | 199.1 | 180.7 | 179.6 |
| Cu. ft. air entering inlet per hr. | 50,460 | 53,880 | 57,120 | 50,760 | 52,740 |
| Wt of air entering inlet per min., lb. | 60.15 | 65.00 | 68.30 | 60.30 | 64.20 |
| Wt. of air leaving registers per min., lb. | 59.76 | 67.15 | 71.16 | 64.31 | 68.11 |
| Heat put into air per hr. at bonnet, B.t.u. | 84,200 | 107,500 | 132,000 | 100,500 | 106,000 |
| Ave. temp. of flue gases, deg. F. | 458 | 554 | 676 | 572 | 575 |
| Overall efficiency* of furnace, per cent | 54.20 | 59.70 | 58.20 | 57.20 | 60.66 |
| Heat loss in dry flue gas, per cent | 8.82 | 10.62 | 12.98 | 10.85 | 11.46 |
| Heat loss in water vapor, per cent | 4.30 | 3.89 | 4.16 | 4.00 | 4.06 |
| Heat loss by radiation, and unaccounted for, per cent | 32.68 | 25.79 | 25.66 | 27.95 | 23.82 |
| Vel. in leaders, ft. per min. 1st floor (average) | 131 | 148 | 167 | 145 | 144 |
| Vel. in leaders, ft. per min., 2d floor (average) | 226 | 252 | 271 | 257 | 261 |
| Vel. in leaders, ft. per min., 3d floor (average) | 274 | 307 | 332 | 275† | 310 |
| B.t.u. available per sq. in. leader, 1st floor (average) | 67 | 91 | 120 | 89 | 89 |
| B.t.u. available per sq. in. leader, 2d floor (average) | 104 | 140 | 172 | 143 | 146 |
| B.t.u. available per sq. in. leader, 3d floor (average) | 142 | 191 | 234 | 165† | 192 |
| Barometer, inches mercury | 29.28 | 29.43 | 28.98 | 29.18 | 29.37 |

*These efficiencies are based upon weight of air as measured at inlet, and bonnet temperature corrected for radiation by the method already indicated. See Table 2.

†3d floor leaders dampered.

TABLE 6

SUMMARY OF THE COMPLETE PLANT TEST OF APRIL 23, 1919, FOR EFFICIENCY AND CAPACITY, No. A-1

WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

Date 4-23-19
Name Furnace Staff

Subject Efficiency and Capacity Test – 150° Equivalent Reg. Temp.

Air Sheet — Bar. 29.28 Hg.

| No. | Leader Size | Register Number | Av. Anemometer Rdg./min. | Av. Temp. Deg. F. at Reg. | True Velocity Ft./min. | Free Area of Reg. sq.ft. | Cu. Ft. of Air per min. | Density | Lb. Air per min. | Distrib. to Each Floor by wt., % | Stack Velocity ft./min. | Leader Velocity ft./min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 12 in | 1 | 89 | 178.0 | 159 | 0.684 | 108.8 | 0.0610 | 6.64 | | | 140 |
| 2 | 12 " | 3 | 67 | 165.0 | 135 | " | 92.4 | 0.06225 | 5.74 | | | 118 |
| 3 | 12 " | 7 | 87 | 180.5 | 157 | " | 107.3 | 0.0607 | 6.51 | 25.02 lb. | | 138 |
| 4 | 12" | 9 | 76 | 170.0 | 145 | " | 99.2 | 0.0617 | 6.12 | 41.9 % | | 128 |
| 5 | | | | | | | | | | | | |
| 6 | 9" sing. | 2 | 140 | 161.0 | 195 | 0.458 | 89.4 | 0.0626 | 5.59 | | 314 | 207 |
| 7 | 8" dbl. | 4 | 133 | 163.8 | 188 | " | 86.1 | 0.0624 | 5.37 | | 354 | 253 |
| 8 | 8" sing. | 8 | 118 | 161.8 | 172 | " | 78.8 | 0.0626 | 4.94 | 21.60 lb. | 324 | 232 |
| 9 | 9" dbl. | 10 | 145 | 165.8 | 200 | " | 91.6 | 0.0622 | 5.70 | 36.2 % | 321 | 212 |
| 10 | | | | | | | | | | | | |
| 11 | 9" sing. | 5 | 190 | 167.8 | 246 | " | 112.8 | 0.0619 | 5.49 | 13.14 lb. | 447 | 253 |
| 12 | 9" dbl. | 6 | 217 | 180.4 | 275 | " | 126.1 | 0.0607 | 7.65 | 21.9 % | 521 | 295 |
| 13 | | | | | | | | Total | 59.76 | | | |
| 14 | | Inlet | 140.5 | 84.6 | 152 | 5.535 | 841 | 0.0715 | 60.15 | | | |
| 15 | | | | | | | | | | | | |

| No. | Reg. No. | A. Temp. Deg. F. at Boot | Av. Temp. Drop in Stack | † B.t.u. per min. – based on Reg. Temp. | ‡ B.t.u. per min. based on app. Bon. net Temp. | | Kind of Stack | Ratio Stack to Leader Area | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | Reg. | | | | | | | | | | |
| 17 | No. | | | | | | | | | | |
| 18 | | | | | | | | | | | |
| 19 | | | | | | | | | | | |
| 20 | 1 | | | 149 | 158 | | | | | | |
| 21 | 3 | | | 111 | 120 | | | | | | |
| 22 | 7 | | | 150 | 159 | | | | | | |
| 23 | 9 | | | 125.5 | 134 | | | | | | |
| 24 | | | | | | | | | | | |
| 25 | 2 | 168.3 | 7.3 | 103 | 120 | | Single | 0.66 | | | |
| 26 | 4 | 165.0 | 1.2 | 102 | 113 | | Double | 0.72 | | | |
| 27 | 8 | 171.0 | 9.2 | 92 | 109 | | Single | 0.72 | | | |
| 28 | 10 | 171.5 | 5.7 | 111 | 130 | | Double | 0.66 | | | |
| 29 | | | | | | | | | | | |
| 30 | 5 | 187.2 | 19.4 | 109 | 141 | | Single | 0.56 | | | |
| | 6 | 196.6 | 16.2 | 176 | 216 | | Double | 0.56 | | | |

1st Floor; 2nd Floor; 3rd Fl.

† Wt. of Air x .24 $(t_R - t_I)$. ‡ Wt. of Air x .24 $(t_B - t_I)$

$t_R$ = Register Temp. $t_B$ = Bonnet Temp. $t_I$ = Inlet Temp.

The heat carried away in the dry flue gases was 8.82 per cent and that lost in water vapor in the flue gases was 2.56 per cent, so that only 65.38 per cent is accounted for. This means that over 34 per cent of the heat value of the coal burned was lost from the furnace casing and bonnet by radiation or in some unaccounted for manner.

Attention should be directed to the fact that in this test the actual weight of air entering the furnace as measured at the inlet was 60.15 lb.

per min. The sum of the weights of air leaving the 10 register faces was 59.76 lb. or only 0.65 per cent less. In all tests, this agreement must be close or else the test must be rejected.

In order to determine the true significance of this radiation loss, a fourth test No. A-4 was run with the same register temperatures as in No. A-2 but with a heavy layer of heat insulation material consisting of 1½ inches of hair felt around the entire furnace and bonnet. The effect of this covering as well as the relation between efficiencies at various register temperatures is shown in the curves of Fig. 18. In

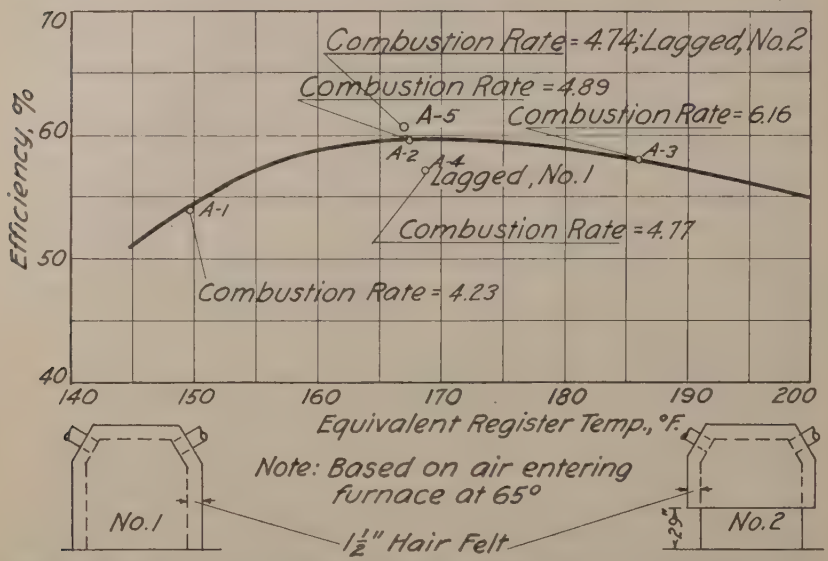



Fig. 18. Efficiency Curve for a Furnace When Installed as Shown in Figs. 15 and 16, Operating at Various Register Temperatures, and Rates of Combustion

addition to test No. A-4 a fifth test was run with the covering removed from the lower casing section of the furnace, and the results are tabulated and plotted as test No. A-5. No explanation is offered concerning these results until more data are available. It must be clearly understood that each of these tests must be checked by duplicate runs, which may affect the shape of the curves somewhat, but will not materially change their significance. In fact, this curve is so important that check tests should be run over the entire range of register temperatures from 120 to 190 deg. F. at intervals of not more than 10 deg. F.

## V. The Auxiliary Plant

In order to make a special study of leaders, stacks, boots, registers and the heat insulation of leaders and stacks, an auxiliary plant (Figs. 19 and 20) has been erected. This plant consists of a single leader and stack connected to a heavily insulated casing 48 inches in diameter, which is equipped with a series of high pressure steam coils. The temperature of the steam and water of condensation is kept under careful observation so that it is readily possible to make an accurate calculation of the air passing through the system since the weight of steam is recorded for every test. This calculation is based on the simple fact that the heat given up by the steam is equal to the heat put into the air except for a very small amount of heat lost by radiation, for which due allowance is made.

The same type of register box and face is used at the head of the stack as is now in service on the main plant. It is, therefore, possible to use the same anemometer calibration and measure the air handled by this single leader and stack at the register as well as by the steam condensed in the coil. The data given (see table in Fig. 20) from the first test on this plant show how well the amounts of air measured by these two methods check each other. This agreement of values is most significant as it shows that there can be no great error in the method involved in the use of a calibrated anemometer in front of a register face.

An elaborate series of tests is now in progress on this plant, and only a few results from the tests so far run are submitted herewith to show the character and value of the information obtainable. These data are based on a study of a second story leader and stack with a 10-inch uncovered leader supplying, (1) a 10-inch round stack, (2) a square stack, (3) a rectangular stack with sides in the ratio of 2:1, and (4) a rectangular stack with sides in the ratio of 4:1. In this first series of tests, the four stacks and the leader all have exactly the same cross-sectional area. The next series of tests will provide for rectangular stacks having first only one-half and secondly three-quarters the area of the leader.

All tests will be run with the same register temperatures for both the full size and for the restricted stacks. By controlling the flow of

steam to the steam coils, various sets of register temperatures are easily obtained.

After these tests have been run the value of covering and the relative efficiency of single and double wall stacks will be determined. It will be noted in the tests reported from the auxiliary plant that the heat loss in the leaders and stacks has been computed as well as the loss in temperature between the bonnet and boot, and again between the boot and register head, for uncovered bright tin pipes.

Additional data will be available for presentation on this part of the work which is in charge of V. S. Day, who will make a separate report on it at the June meeting of the Association.

Fig. 19. The Auxiliary Plant Showing the Wahlen Gage in Use on a Round Leader and Stack of the Same Area

WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

Date 5-5-19
Name V. S. Day

Subject Results of Tests on Auxiliary Plant with Uncovered 10" Leader and 10" Stack.

Note: Length of Leader 10'-0" and Height of Stack 18'-0"

| No. | Date | Regs. Temp. °F. | Inlet Temp. °F. | Diff Regs to Inlet | Equiv. Regs. Temp. above 65° | Temp. Loss in Leader | Temp. Loss in Stack | Temp. Loss, Bonnet to Regs. | B.t.u. Loss % in Stack | 18 B.t.u. Loss % in Leader | B.t.u. Loss % Bonnet to Reg. | Total B.t.u. out into Air per hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4-24-19 | 119.7 | 70.5 | 49.2 | 114.2 | 3.95 | 7.33 | 11.30 | 12.13 | 6.55 | 18.68 | 9840 |
| 2 | 4-25-19 | 117.6 | 72.0 | 45.6 | 110.6 | 4.10 | 7.10 | 11.20 | 12.50 | 7.22 | 19.72 | 10300 |
| 3 | | | | | | | | | | | | |
| 4 | 4-24-19 | 135.5 | 70.0 | 65.5 | 130.5 | 4.15 | 8.65 | 12.80 | 11.05 | 5.30 | 16.35 | 15800 |
| 5 | 4-25-19 | 136.3 | 72.0 | 64.3 | 129.3 | 4.20 | 8.80 | 13.00 | 11.40 | 5.43 | 16.83 | 15750 |
| 6 | | | | | | | | | | | | |
| 7 | 4-24-19 | 149.4 | 71.1 | 78.3 | 143.3 | 5.15 | 10.72 | 15.87 | 11.40 | 5.47 | 16.87 | 20100 |
| 8 | 4-25-19 | 149.7 | 72.5 | 77.1 | 142.1 | 5.26 | 10.43 | 15.70 | 11.25 | 5.67 | 16.92 | 19800 |
| 9 | | | | | | | | | | | | |
| 10 | 4-24-19 | 160.5 | 72.4 | 88.1 | 153.1 | 6.00 | 11.45 | 17.45 | 10.85 | 5.68 | 16.53 | 23300 |
| 11 | 4-25-19 | 161.8 | 72.1 | 89.7 | 154.7 | 6.65 | 11.55 | 18.20 | 10.70 | 6.16 | 16.86 | 24650 |
| 12 | | | | | | | | | | | | |
| 13 | 4-24-19 | 177.6 | 70.2 | 107.4 | 172.4 | 19.60 | 15.60 | 35.20 | 11.10 | 13.90 | 25.00 | 20000 |
| 14 | 4-25-19 | 179.0 | 72.0 | 107.0 | 172.0 | 16.15 | 17.00 | 33.15 | 12.10 | 11.50 | 23.60 | 20800 |

| Date | Regs. Temp | Wt. of Air per hr. by steam | Vol. of Air per hr. boot temp. | Vel. of Air at boot temp. | B.t.u. per sq. in. Leader above 70° | Vel. of Air at Reg. gr. ft/sec. | Room Temp. at ½ hgt. of plant | |
|---|---|---|---|---|---|---|---|---|
| 4-24-19 | 119.7 | 6780 | 14750 | 5.11 | 226.5 | 4.05 | 69.2 | |
| 4-25-19 | 117.6 | 7530 | 16200 | 5.60 | 244.0 | 4.44 | 71.9 | Notes: In 1st test, 4-24-19, one inlet damper closed. |
| 4-24-19 | 136.5 | 8400 | 18750 | 6.49 | 323.0 | 5.13 | 71.4 | |
| 4-25-19 | 136.3 | 8500 | 19000 | 6.56 | 324.0 | 5.19 | 73.7 | |
| 4-24-19 | 149.4 | 8910 | 21050 | 7.28 | 378.0 | 5.73 | 71.4 | In two last tests, 4-24-19 and 4-25-19, one damper closed and other throttled. |
| 4-25-19 | 149.7 | 8900 | 21000 | 7.27 | 374.0 | 5.74 | 73.8 | |
| 4-24-19 | 160.5 | 9200 | 21400 | 7.40 | 417.0 | 5.83 | 70.2 | |
| 4-25-19 | 161.8 | 9520 | 21150 | 7.67 | 436.0 | 6.05 | 72.8 | |
| 4-24-19 | 177.6 | 6930 | 14200 | 4.91 | 322.0 | 3.85 | 69.0 | |
| 4-25-19 | 179.0 | 6200 | 14960 | 5.18 | 336.0 | 4.05 | 71.3 | |

$t_2$ = inlet temperature
$t_1$ = bonnet "
$t_3$ = boot "

† B.t.u. loss in Leader in % = $\frac{W \times .24 (t_1 - t_2)}{W \times .24 (t_1 - t_3)} \times 100$.
W = weight of air flowing per hr. based on heat given up by steam less 2%.

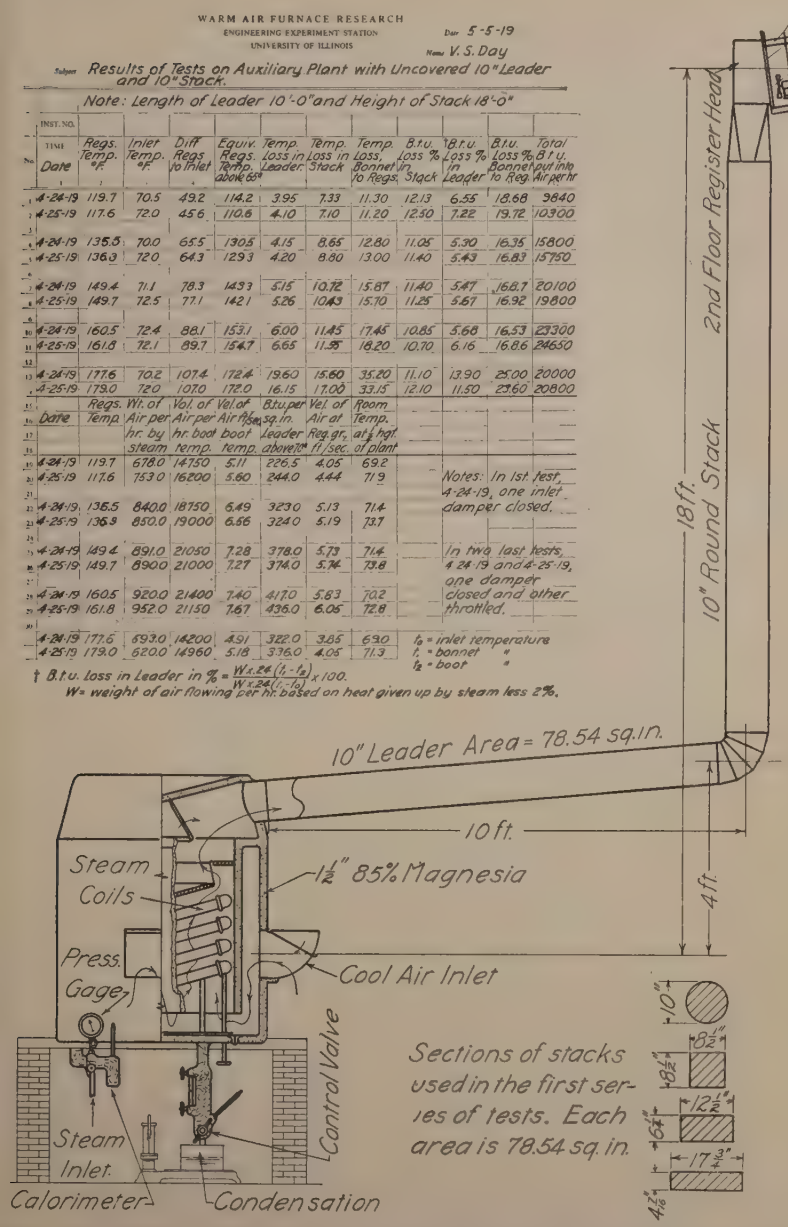



FIG. 20. SECTIONAL ELEVATION OF AUXILIARY PLANT SHOWING STEAM HEATED CASING CONNECTED TO SINGLE LEADER, STACK, AND REGISTER

## VI. Discussion of the Present Program of Investigation

The objects of this investigation have already been stated in Section I, but it may not be evident from that summary just what the Research Staff has been doing, is now engaged in, and plans to undertake next. For that reason, the following program of activities may help to give a clearer idea of the progress of this work.

(1) A satisfactory method for measuring temperatures at many points had to be developed. This has been done as indicated in Section II and has been in successful operation for several months, and is accurate within 1 or 2 degrees.

(2) The problem of measuring the inflow of cold air at the furnace inlet and the outflow of heated air at numerous register faces occupied a great deal of time. A solution has been found in the method already described in Section III, and the average results are accurate within 1 per cent.

(3) The first actual testing problem was an investigation of the effect of register temperature on the heating and air handling capacity of a complete furnace plant. This work has been done and the results reported in Section IV with a recommendation that for the maximum load conditions in practice the register temperatures should be taken as high as 175 to 185 deg. F., but for average conditions the register temperature should not *exceed* 150 deg. F.

(4) The next actual testing problem was a determination of the variation in efficiency and capacity of a furnace with various register temperatures. This, of course, also involved the effect of various rates of combustion on the efficiency and capacity of a furnace. In no case must the rate of combustion at any time require a draft in excess of 0.2 inch water gage. As hard coal is used, the length of firing period can also be determined. These tests are now in progress and some of the results have been reported and discussed in Section IV.

(5) The heat and air-carrying capacities, and the heat losses of various kinds and sizes of leaders and stacks has long been an open question. Data on losses through various types of boots and registers have also been lacking. All these problems and others involving the length and pitch of leaders as well as the heights of and offsets in stacks are being solved by the tests now in progress with the auxiliary plant. Some of the results of this work are reported in Section V.

(6) A comparison of data on the relative efficiency and capacity of various furnaces of the same grate area and firepot capacity but with different amounts and arrangements of heating surface was one of the first objects suggested by the members of the Association. The tests on a solid firepot, ring-radiator furnace are now in progress. A furnace without radiator having a single combustion chamber will be tested next.

(7) A comparison between hard and soft coal furnaces of the same grate area and firepot capacity should be made as early in this work as possible.

(8) A study of cold air or recirculating connections has been provided for in the present main plant, and data will be taken on the effect of velocities in, and shape of the inlet, as well as the allowable friction loss in the same.

(9) A standard method of rating furnaces is also to be developed as a result of a study of the data secured in the foregoing tests.

(10) Finally, the effect of modifications in design and installation as suggested from a study of the best performance found in these tests should be investigated. It is along this line that the furnace industry must expect to profit most effectively from this work.

## VII. Application of Test Data to the Design of Warm-Air Furnace Heating Installations

It is, of course, necessary to wait until more test data are available before making final recommendations as to the proper procedure, and the most suitable values to use in designing a furnace heating system. It may not, however, be out of place to discuss a simple application of the data so far obtained to a typical furnace heating design problem using such values as are now available. In the following discussion based on the problem presented by W. E. Pratt it has been found necessary to use register temperatures as high as 185 deg. F. for the first floor leaders. It is undoubtedly desirable, however, to use a lower range of register temperatures, with a maximum outlet temperature of not over 175 deg. F., whenever possible.

Curves (Fig. 22) have been plotted from the data obtained in seven tests on the main plant, showing the relation between the register temperatures on any floor, and the B. t. u. carried per square inch of leader pipe per hour to each of these floors.

Knowing the B. t. u. loss per hour from any room on any floor (first, second or third) and given any register temperature, using the value of B. t. u per square inch of leader pipe from these curves, simple division will give the square inch of leader pipe necessary to heat the room to 70 deg. F., on a zero day.

Taking the first floor rooms of the house plan shown in Fig. 21, and assuming a register temperature for a zero day of 185 deg. F. from the curve for the first floor, it is evident that one square inch of leader pipe will carry 115 B. t. u. per hour to the rooms. Then dividing the B. t. u. loss per hour from the room by 115 gives the number of square inches of leader pipe necessary to heat the room on a zero day.

From the test data (Table 2) it is apparent that the temperature at the registers on the second floor is approximately 10 degrees lower than that on the first floor, or about 175 deg. F. In like manner from the second floor curve it is found that one square inch of leader pipe at this temperature will supply 160 B. t. u. per hour. Dividing the heat loss from the second floor rooms by this value gives the square inches of leader pipe necessary to offset the heat loss from the second floor rooms.

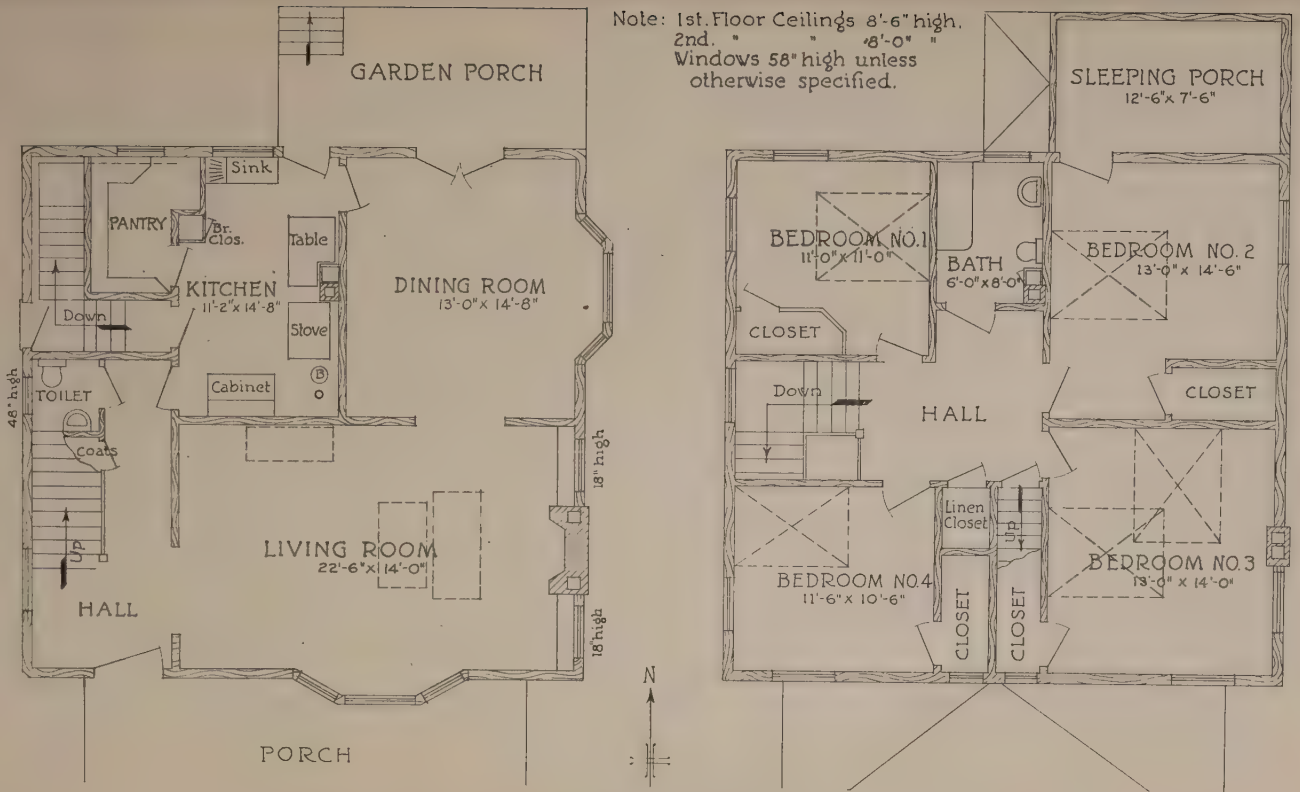



FIG. 21. FLOOR PLANS OF HOUSE USED IN TYPICAL DESIGN PROBLEM

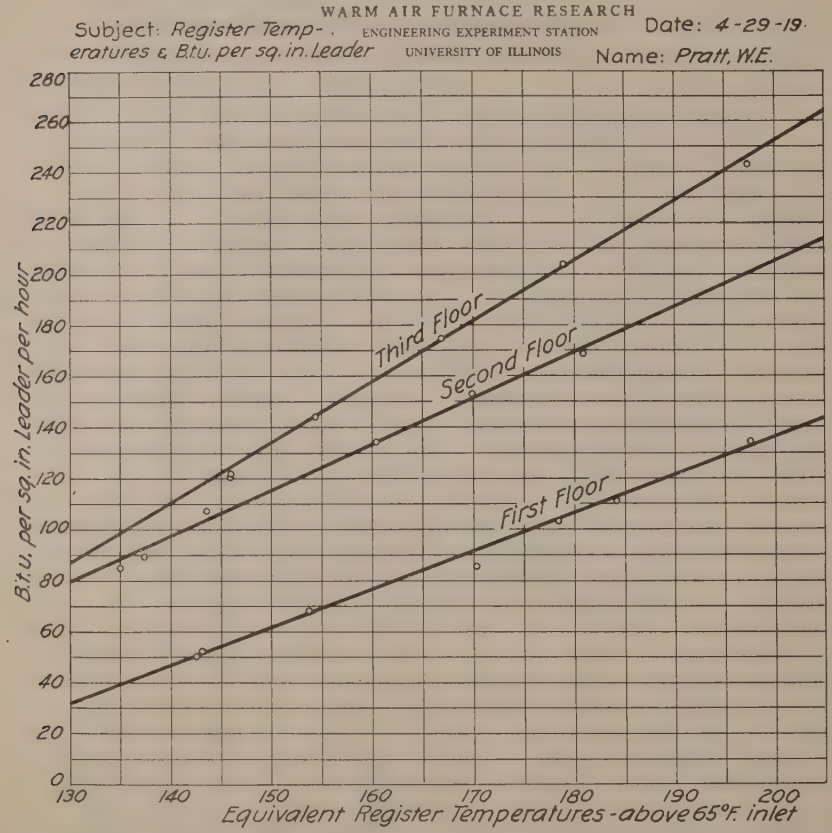



Fig. 22. Curves Showing Effect of Register Temperature on Leader Capacity

In like manner the test data show a register temperature on the third floor that is about the same as that on the first floor. From the third floor curve it will be seen that at 185 deg. F. register temperature one square inch of leader pipe will carry 215 B. t. u. per hour. The square inches of leader pipe for the third floor rooms is found as before.

In plotting the curves, the average register temperature for any one floor was used in each case. It will be noted from the typical test data (Table 6) that there is a considerable variation in register temperatures on any one floor. It is therefore evident that the size of the pipe as figured may not be absolutely correct in each case. It is not much

in error, however, and in view of the large increase in pipe areas from one size to the next, the error is negligible for all practical purposes.

It is quite evident that the design of a furnace heating system must be based on the B. t. u. loss per hour from each room. This method of computation is quite familiar to the engineer and can be used by any well qualified furnace man, as fairly simple formulas can be made to cover most types of installation. A later bulletin will cover such applications, and therefore no space is given to the calculation of heat losses here.

It is found that the living room on the first floor of the house under consideration has a heat loss of about 16,600 B. t. u. per hour. With a register temperature of 185 deg. F., each square inch of leader supplies 115 B. t. u. and the calculated area becomes

$$\frac{16{,}600}{115} = 144 \text{ sq. in.}$$

which requires either one 9-inch and one 10-inch leader, or a special 13½-inch leader.

Following is a table showing the heat loss in B. t. u. per hour from each room of the typical house (Fig. 21), and the size of leader pipe as previously figured. The size leader that would be installed based on the results as figured and the actual areas of same are also given. Stacks are assumed of common commercial sizes as the plant from which the data were secured has the common commercial size stacks. These are approximately 0.7 of the leader area for the second floor, and 0.6 of the leader area for the third floor.

As test data are not yet available on stacks and registers no attempt has been made to discuss the design of this part of the system. It is also assumed that all the preceding leaders are short and straight. The effect of long runs and elbows in leaders is being investigated in tests run on the auxiliary plant.

TABLE 7

HEAT LOSS DATA AND LEADER SIZES FOR A TYPICAL FURNACE PROBLEM

| Room | B. t. u. Loss per Hour | Size Pipe by Test Data Sq. In. | Size Pipe by Install. In. | Area Sq. In. |
|---|---|---|---|---|
| **FIRST FLOOR** | | | | |
| Living room | 15590 | 144 | 1–9 and 1–10 | 143 |
| Dining room | 14040 | 121 | 12 | 113 |
| Kitchen | 8980 | 78 | 10 | 78 |
| Hall | 11810 | 103 | 12 | 113 |
| Toilet | 2287 | 19 | 8* | 50 |
| **SECOND FLOOR** | | | | |
| Bedroom No. 1 | 6990 | 44 | 8 | 50 |
| Bedroom No. 2 | 8670 | 54 | 9 | 64 |
| Bedroom No. 3 | 8335 | 52 | 9 | 64 |
| Bedroom No. 4 | 7245 | 45 | 8 | 50 |
| Bath | 3254 | 20 | 8* | 50 |
| **THIRD FLOOR (assuming same rooms as second floor)** | | | | |
| Rooms same as second floor with 20 per cent greater heat loss | 8400 | 40 | 8 | 50 |
| | 10404 | 48 | 8 | 50 |
| | 10000 | 47 | 8 | 50 |
| | 8700 | 40 | 8 | 50 |
| | 3900 | 18 | 8* | 50 |

*No size used commercially less than 8-in. diameter pipe.

## VIII. The Organization of the Furnace Research Staff and the Advisory Committee

The terms of the agreement between the Association and the University provide for a staff composed of at least two full-time research associates and one half-time research assistant working under the supervision of the Engineering Experiment Station. In addition to these men, this work is to be carried on in consultation with an Advisory Committee on Furnace Research appointed by the President of the Association.

It was found impossible to assemble the complete research staff at the time the coöperative agreement became effective, and it was not until October 17, 1918, that the first man reported for duty. In the meantime a large amount of preliminary work had been done by Professors Willard and Kratz in getting the original plant equipped and in developing the calibrating plants. As soon as Prof. S. L. Simmering arrived, F. G. Wahlen was detailed to assist him, and Professor Kratz has devoted an increasing amount of his time to the work since October 1. With the addition of V. S. Day on December 18, 1919, and finally of W. E. Pratt on January 16, 1918, a very effective organization has been perfected and the work has been progressing rapidly and effectively, since January of this year. It should also be noted that at all times there have been available one or more machinists and mechanics of the Mechanical Engineering Department as well as F. W. Stearns (special mechanic) who has been of the greatest assistance in taking data on many tests. In the operation of the main plant on a complete 10 to 12 hour test at least five men are absolutely necessary.

The personnel of the Research Staff has been made up as given on the following page.

FURNACE RESEARCH STAFF

DEAN C. R. RICHARDS . *Dean College of Engineering and Director Engineering Experiment Station.*
PROFESSOR A. C. WILLARD . . *Professor Heating and Ventilation*
PROFESSOR A. P. KRATZ . . . . *Research Assistant Professor*
PROFESSOR S. L. SIMMERING* . . . . . *Research Associate*
MR. F. G. WAHLEN . . . . . *Research Graduate Assistant*
MR. V. S. DAY† . . . . *Research Assistant and Acting Secretary*
MR. W. E. PRATT‡ . . *Special Investigator and Research Associate*

The Advisory Committee held its first meeting at the University on December 17, 1918. R. C. Cook was unable to be present at this meeting, and W. A. Tuerre represented Walter Wimmer. Since then, both J. M. McHenry and P. J. Dougherty have been frequent visitors at the University and have kept in close touch with the progress of the work. The present program of investigation as given in Section VI of this Bulletin was outlined at the time of this meeting in joint conference with the members of the research staff. The complete organization of this committee follows:

ADVISORY COMMITTEE ON FURNACE RESEARCH

MR. J. M. MCHENRY, *Chairman*
*Manager of the Furnace Department*
*Detroit Stove Works*
*Detroit, Michigan.*
MR. P. J. DOUGHERTY,
*Heating Engineer, International Heater Company*
*Utica, New York.*
MR. R. C. COOK,
*Manager, Thatcher Furnace Company*
*Chicago, Illinois.*
MR. WALTER WIMMER,
*Manager, Furnace Department*
*Wrought Iron Range Company*
*St. Louis, Missouri.*
MR. E. S. MONCRIEF,
*Vice-President, The Henry-Miller Foundry Company*
*Cleveland, Ohio.*

*Appointed October 18, 1918. Resigned March 31, 1919. ‡Appointed January 16, 1919.
†Appointed December 18, 1918.

## IX. Recommendations to the Association Concerning the Future of this Investigation

The work so far accomplished has already shown that a great many factors vitally affecting the design and operation of furnaces and furnace heating systems have not only not been determined but their effect has not even been correctly estimated. The unusual difficulties encountered in the accurate measurement of the air flowing through such a system under natural conditions have proved the most serious obstacle in this undertaking. Enough testing work has been done, however, to show that most of the undetermined factors referred to can be measured, and the results interpreted in such form as to be of practical use to the furnace industry, as set forth in the preceding pages of this Bulletin.

It is therefore recommended that this investigation should be continued under the same terms as those of the present coöperative agreement which expires October 1, 1919. It is further suggested that if a new agreement is entered into after October 1, 1919, it will be well to consider the desirability of providing for an advisory engineering service for the benefit of all members of the Association. Such a service would include the interpretation of the results of this investigation in the solution of problems in furnace design and rating and in the layout and installation of furnace heating systems.

# APPENDIX I—FINANCIAL STATEMENT

**Expenditures by the National Warm Air Heating and Ventilating Association since Oct. 1, 1918**

| | | | |
|---|---|---|---|
| A. | *Salaries:* | | |
| | 1. S. L. Simmering* Oct. 18 to April 1 | $1100 | |
| | 2. V. S. Day Dec. 17 to May 1 | 448 | |
| | 3. W. E. Pratt Jan. 16 to May 1 | 800 | |
| | Total | | $2348.00 |
| B. | *Labor:* | | |
| | 1. For mechanics' labor on plant: | | |
| | Total | | 354.00 |
| C. | *Materials*† (This includes labor for work done in shops other than the testing laboratory) | | |
| | Coal, furnace work, instruments, auxiliary plant, etc.: | | |
| | Total | | 1053.35 |
| | Grand total | | 3755.35 |
| | Total expenditure | 3755.36 | |
| | Fund appropriated | 8000.00 | |
| | Remainder, unexpended, May 1, 1919 | $4244,64 | |

**Expenditures by the University since January 1, 1917**

| | | | |
|---|---|---|---|
| A. | *Salaries:*‡ | | |
| | 1. A. P. Kratz (Estimated at approximately half time for one year) | $1200.00 | |
| | 2. F. G. Wahlen | 350.00 | |
| | Total | | $1550.00 |
| B. | *Labor:* | | |
| | Draftsmen and Mechanics | | 700.00 |
| C. | *Main Plant:* | | |
| | Materials and Labor | | 886.58 |
| D. | *Instruments:*§ | | 225.62 |
| E. | *Calibrating Plants:* | | |
| | Materials and Labor | | 132.85 |
| | Grand total | | $3495.05 |

*Resigned March 31, 1919.

†Present furnace and piping donated by members of the Association.

‡This does not include any charges for supervision by A. C. Willard.

§Not inclusive of instruments supplied from the instrument room of the Mechanical Engineering Laboratory.

This list does not include charges for materials drawn from University stock.

## APPENDIX II—THE AGREEMENT BETWEEN THE ASSOCIATION AND THE UNIVERSITY

ARTICLES OF AGREEMENT between the National Warm-Air Heating and Ventilating Association and the Board of Trustees of the University of Illinois for a co-operative investigation of Warm-Air Furnaces and Furnace Heating Systems by the Engineering Experiment Station of the University of Illinois under the following terms and conditions:

I. This agreement is executed for a period of one year beginning October 1, 1918, with the understanding that it may be extended for additional similar periods under the same or such other terms as may be mutually agreed upon.

II. The Engineering Experiment Station will supervise and direct all testing work and the computation of all results obtained; it will furnish the furnace testing plant now installed in the Mechanical Engineering Laboratory, together with all testing instruments necessary in the investigation. Should important changes in or additions to the present testing plant become necessary, it is agreed that the cost thereof shall be charged against the fund provided by the National Warm-Air Heating and Ventilating Association for the general investigation as hereinafter provided.

III. An advisory committee of the National Warm-Air Heating and Ventilating Association shall be appointed to consult with the officers of the Engineering Experiment Station concerning the conduct of the investigation and the general testing program to be undertaken. When a general program of tests has been agreed upon, the conduct of the tests shall be entirely under the control of the Engineering Experiment Station, which is necessarily responsible for the results secured.

IV. All of the original test data and the computations and results of the investigation are to be the property of the Engineering Experiment Station and they are to be kept on file at the University of Illinois. Furthermore, it is understood and agreed that the Engineering Experi-

ment Station shall have the exclusive right to publish the results of the tests and investigations conducted under this agreement, and no publicity to any of the tests shall be given prior to the publication of the results by the Engineering Experiment Station.

V. The advisory committee or other authorized representative of the National Warm-Air Heating and Ventilating Association shall at all times have access to the data secured and the computed results, and one copy thereof shall be furnished the Secretary of the National Warm-Air Heating and Ventilating Association subject, however, to the conditions named in Article IV. The Engineering Experiment Station will submit a semi-annual report on the work in progress, in addition to the data and results, to the National Warm-Air Heating and Ventilating Association.

VI. Not less than two full time testing assistants and one half-time assistant will be needed to conduct the investigation herein contemplated. The salaries of these assistants and of any other assistants later found necessary are to be paid from the funds provided by the National Warm-Air Heating and Ventilating Association. These assistants are to be considered members of the staff of the Engineering Experiment Station during their connection therewith.

VII. All furnaces tested are to be furnished and erected at the testing plant without expense to the Engineering Experiment Station. All expenses connected with the preparation of the furnaces for testing and any other expense connected with these tests, not otherwise provided for, shall be paid from the funds furnished by the National Warm-Air Heating and Ventilating Association.

VIII. On or before October 10, 1918, the National Warm-Air Heating and Ventilating Association shall pay to the Board of Trustees of the University of Illinois an initial sum of two thousand dollars ($2,000.00) and thereafter it shall maintain in this special fund for furnace testing a balance of not less than five hundred dollars ($500.00) to be administered by the Comptroller of the University and paid out by him on vouchers approved by the Director of the Engineering Experiment Station. It is further agreed that the total amount of the fund expended by the National Warm-Air Heating and Ventilating Association shall not exceed eight thousand dollars ($8,000.00) for the first

year of this agreement. At the termination of this agreement or at any time on the request of the Association, the Comptroller shall render an accounting to the National Warm-Air Heating and Ventilating Association, and he shall return to the Association any unexpended balance which may remain in this fund at the termination of this agreement.

The Board of Trustees of the University of Illinois

[Signed]
*Lloyd Morey*, Comptroller.
*Allen W. Williams*,
Secretary, N. W. A. H. & V. A.

Witnesses: *H. E. Cunningham*,
Secretary, University of Illinois.
*Bess D. Fritz.*